TUM INSIGHTS

TUM Forum Sustainability

# Circular Economy

**Edited by Ralf Reichwald**
Magnus Fröhling • Birgit Herbst-Gaebel
Michael Molls • Peter Wilderer

TUM Senior Excellence Faculty

TUM.University Press

„Wissenschaftler und Ingenieure stehen vor einer gewaltigen Aufgabe: Sie müssen der Gesellschaft den Weg in Richtung eines ökologisch nachhaltigen Managements des Planeten im Zeitalter des Anthropozäns weisen.“

“Scientists and engineers face a daunting task: to lead society in the Anthropocene era towards ecologically sustainable management of the planet.”

**Paul Crutzen**
Nobel Prize winner, Founding and honorary member of the Institute for Earth System Preservation (IESP)

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**Ralf Reichwald**
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**Ralf Reichwald**
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**Organizer**
TUM Senior Excellence Faculty

**in cooperation with**

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Institute for Earth System Preservation
European Academy of Sciences and Arts
Saxon Academy of Sciences and Humanities

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# Dank der Herausgeber

Die Initiative zur Durchführung des Symposiums zum Thema „Circular Economy“, auf dessen Ergebnissen dieses Buch basiert, geht auf eine intensive Diskussion im Board der TUM Senior Excellence Faculty zurück, gefolgt von einer Workshop-Reihe im Zeitraum vom 16. April bis 11. Juni 2021. Wir, die Organisatoren dieses Symposiums und Mitglieder des Boards, danken an dieser Stelle allen, die sich für das Gelingen dieses Projektes eingesetzt haben.

Insbesondere bedanken wir uns bei Herrn Staatsminister Dr. Florian Herrmann, unter dessen Schirmherrschaft das Symposium und die Erarbeitung des vorliegenden Buches stand. Dank gebührt auch dem Präsidenten der TU München, Herrn Prof. Thomas Hofmann, sowie dem Vizepräsidenten für Forschung, Herrn Prof. Gerhard Kramer, dessen Anliegen es ist, eine breit angelegte und wissenschaftlich fundierte Nachhaltigkeits-Strategie für die TU München zu erarbeiten und zu realisieren. Das Thema „Circular Economy“ wird ein wichtiger Baustein dieser Strategie sein.

Ein besonderer Dank gebührt Herrn Prof. Thomas Hamacher (TUM-Lehrstuhl für erneuerbare und nachhaltige Energiesysteme), der im Wintersemester 2020/2021 in Vorbereitung des Symposiums ein gleichnamiges Online-Seminar „Circular Economy“ veranstaltet hat. Eine international besetzte Studentenschaft hat an diesem Seminar teilgenommen. Die Ergebnisse dieses Seminars waren sehr hilfreiche Beiträge für die Vorbereitungen des Symposiums.

Ein weiterer Dank geht an die Vorsitzenden der oben genannten Workshops, nämlich Prof. Georg Färber, Prof. Thomas Hamacher, Prof. Erik G. Hansen, Dr. Sicco Lehmann-Brauns, Prof. Klaus Mainzer, Prof. Winfried Petry und Prof. Manuela Wimmer.

Die Durchführung des Symposiums sowie die Ausarbeitung des vorliegenden Buches wurden maßgeblich durch das „TUM Institute for Advanced Study“, das „Institute for Earth System Preservation“, die „European Academy of Sciences and Arts“ und die „Saxon Academy of Sciences and Humanities“ unterstützt. Allen Mitarbeitern dieser Institutionen danken wir für ihre Unterstützung.

Nicht zuletzt danken wir den Mitgestaltern des redaktionellen und organisatorischen Designs dieses Buches, dies sind insbesondere Nora Müller (KW NEUN Grafikagentur), Dr. Katharina Markgraf (TUM.University Press), Caroline Ennemoser (TUM.University Press), Dr. Stacy von Boeckmann (TUM Center for Study and Teaching) und Birgit Reinbold (TUM Senior Excellence Faculty).

**Ralf Reichwald**
Magnus Fröhling
Birgit Herbst-Gaebel
Michael Molls
Peter Wilderer

# Acknowledgements of the Editors

This book is based on the results of the Symposium “Circular Economy” which took place on Juni 11th 2021, following a series of workshops held between April 16 and June 11, 2021. The initiative of the symposium goes back to an intensive discussion in the board of the TUM Senior Excellence Faculty. The editors of this book and organizers of the symposium and members of the board, would like to acknowledge the many people who have facilitated the process of this project.

A special appreciation goes to Minister Dr. Florian Herrmann, who supported with his patronage the symposium and the elaboration of this book. Moreover, we appreciate the support of the President of the Technical University of Munich, Prof. Thomas Hofmann, and the Vice President for Research, Prof. Gerhard Kramer, whose concern is to develop and implement a scientifically based sustainability strategy for the Technical University of Munich. Symposium and book with its topic “Circular Economy” will be an important component of this strategy.

A special acknowledgement goes to Prof. Thomas Hamacher (TUM-chair for renewable and sustainable energy systems), who organized prior to the symposium an online seminar also entitled “Circular Economy” in the winter semester of 2020. An international group of students participated this seminar. The students’ contributions were a significant support to the preparations for the symposium.

Further appreciation goes the chairpersons of the above-mentioned workshops, namely Prof. Georg Färber, Prof. Thomas Hamacher, Prof. Erik G. Hansen, Dr. Sicco Lehmann-Brauns, Prof. Klaus Mainzer, Prof. Winfried Petry und Prof. Manuela Wimmer.

The organization of the symposium and the elaboration of this book were significantly supported by the “TUM Institute for Advanced Study”, the “Institute for Earth System Preservation”, the “European Academy of Sciences and Arts” and the “Saxon Academy of Sciences and Humanities”. We acknowledge all these organizations and their members for their contributions.

A most valuable support came from the network of co-creators and co-designers of this book. Special appreciations for their contributions go to Nora Müller (KW NEUN Grafikagentur), Dr. Katharina Markgraf (TUM University Press), Caroline Ennemoser (TUM.University Press), Dr. Stacy von Boeckmann (TUM Center for Study and Teaching) and Birgit Reinbold (TUM Senior Excellence Faculty).

Der Mensch ist eine erstaunliche Spezies; sie hat unglaubliche Entwicklungen hervorgebracht in den Bereichen Gesundheit, Lebensmittelproduktion und -sicherheit, Energie und Infrastruktur, Transport und effektive Kommunikation über größte Entfernungen hinweg. All dies waren Errungenschaften der letzten paar hundert Jahre. Stellt man sich die auf einen Tag verkürzte Geschichte der Erde vor, dann existieren die ersten Menschen nur eine Minute und 17 Sekunden und wir – der moderne Homo sapiens – nur 4 Sekunden vor Tagesende. Allein im Zuge dieses Wimpernschlags in der Evolution unseres Planeten hat die Menschheit – ohne die langfristigen Folgen ihres Handelns zu bedenken – mit ihren kohlenstoff- und ressourcenintensiven Wirtschaftsmodellen zur zunehmenden Erderwärmung beigetragen.

Unsere heutigen Wirtschaftsweisen und Verbrauchsgewohnheiten bezahlen wir mit der Schädigung der Natur und dem Verlust an Biodiversität in der Luft, auf der Erde und unter Wasser und beschneiden damit die Grundlagen unserer Existenz. Und sie verstärken die Ungleichheit auf unserem Planeten; diejenigen, die am wenigsten Zugang zu den Vorteilen der menschlichen Entwicklung haben, leiden am meisten unter den unerwünschten Nebenwirkungen unseres Handelns. Wir gefährden unsere eigene Zukunft. Und dies erfordert unseren dringenden Handlungsbedarf.

In meiner Antrittsrede als Präsident habe ich betont, dass die Gesellschaft mehr denn je die ganze Gestaltungskraft unserer Universitätsgemeinschaft braucht, unseren unternehmerischen Mut zur Veränderung und ein neues Verantwortungsbewusstsein für ein nachhaltiges Handeln. Deshalb richten wir die Innovationskraft der TUM auf die Potenziale der Kreislaufwirtschaft („Circular Economy") aus, die durch neue Geschäftsmodelle, neue Verfahren und innovative Produkte ökonomische Ziele mit ökologischen und sozialen Aspekten in Einklang zu bringen vermag.

Ich freue mich, Ihnen mit vorliegendem Band das Ergebnis des Symposiums „Circular Economy" vorlegen zu können, welches unsere TUM Senior Excellence Faculty im Sommer 2021 in Kooperation mit renommierten Einrichtungen und mit Expert:innen verschiedenster Fachdisziplinen aus Wissenschaft, Wirtschaft und Politik veranstaltet hat. Ganz besonders freue ich mich, dass bei dieser Initiative auch unsere Studierenden in Form eines begleitenden internationalen Praktikums eingebunden waren. Denn sie sind unsere Hoffnungsträger als Change Agents für eine nachhaltigere Zukunft.

Mit ihrer Reihe „TUM Forum Sustainability" steht unsere TUM Senior Excellence Faculty bereits seit 2016 für engagierte Initiativen im Bereich der Nachhaltigkeit. Mein besonderer Dank gilt an dieser Stelle den Herausgebern der vorliegenden Broschüre, allen voran Ralf Reichwald, der dieser Initiative vorstand und der sie – trotz der großen Einschränkungen durch die Corona-Pandemie – zielstrebig zum Erfolg geführt hat und Michael Molls, der als Sprecher der TUM Senior Excellence Faculty unsere jung gebliebenen Emeritae and Emeriti immer wieder zu beherztem Engagement inspiriert.

Ich wünsche mir, dass die im Symposium erarbeiteten Handlungsempfehlungen zu grenzüberschreitendem Denken und verantwortungsvollem Handeln anregen und damit einen wertvollen Beitrag für eine nachhaltigere Zukunft leisten werden.

# Grußwort
# Greeting

## Professor Dr. Thomas F. Hofmann

Präsident der Technischen Universität München
President of the Technical University of Munich

The human species is astonishing! It has brought about incredible advances in health, food production and safety, energy and infrastructure, transportation and effective communication over vast distances. All of these achievements have occurred in the last few hundred years. If we conceive of the Earth's history condensed to a single day, the earliest humans existed but for a single minute and seventeen seconds, and we – modern Homo sapiens – for a mere 4 seconds before the end of the day. In this blink of an eye in the evolution of our planet alone, humanity – without a thought for the long-term consequences of its actions – has contributed to the acceleration of global warming through its high-carbon, resource-intensive economic models.

We are paying for our current economic practices and habits of consumption by damaging nature and losing biodiversity in the air, on the earth, and underwater, thereby sacrificing the very foundations of our existence. To compound the problem, these practices and habits exacerbate the inequities of our world. Those who have the least access to the benefits of human development suffer the most from the undesirable side effects of our actions. We are putting our own future at risk, and this calls for urgent action.

As I stressed in my inaugural speech as TUM's new president, now more than ever before, society needs the full creative force of our university community, our entrepreneurial courage to embrace change, and our readiness to assume responsibility for sustainable action. It is in this spirit that TUM is focusing its innovative strength on the potential of the circular economy to reconcile our economic objectives with ecological and social responsibility through new business models, new processes, and innovative products.

It is with great pleasure that I present to you the results of the symposium "Circular Economy," organized by our TUM Senior Excellence Faculty in the summer of 2021 in cooperation with renowned institutions and experts from a broad range of disciplines in science, business and politics. I am particularly delighted by the involvement of our students in this initiative in the form of international practical courses. After all, it is they who hold the promise of being agents of change toward a more sustainable future.

With the initiation of its series "TUM Forum Sustainability" in 2016, our TUM Senior Excellence Faculty plays a significant part in upholding our sustainability commitment. I would like to take this opportunity to express my special thanks to the editors of this volume, first and foremost to Ralf Reichwald, who presided over this event and who – despite the significant constraints imposed by the Corona pandemic – single-mindedly led it to success, and to Michael Molls, who, as speaker for the TUM Senior Excellence Faculty, continues to inspire our emeritae and emeriti to such spirited engagement with the challenges facing our world today.

It is my sincerest hope that the recommendations for action formulated at this symposium will inspire thinking across the borders of disciplines and industrial sectors and move us all toward responsible action. In doing so, it will have made a valuable contribution, indeed, to a more sustainable future.

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# Foreword

# Nachhaltigkeit – Circular Economy als politisches Programm

Unsere Welt steht vor gewaltigen Herausforderungen. Dies gilt auch bereits unabhängig vom schrecklichen Krieg in der Ukraine. Wenn die Menschheit überleben will, muss es gelingen, das exponentielle Wachstum von Wissenschaft, Technik und Wirtschaft, das uns seit rund zwei Jahrhunderten so viel Wohlstand und Sicherheit gebracht hat, von dem ebenso exponentiell ansteigenden Verbrauch natürlicher Ressourcen zu entkoppeln. In den Bereichen Rohstoffe und Energie geht es darum, eine beschleunigte Entwicklung nach oben in eine Kurve zu zwingen und in eine den Prozessen der Natur entsprechende Kreislaufwirtschaft einmünden zu lassen. Besonders drängend zeigt sich das Problem bei unserer Energieversorgung. Der Klimawandel zwingt uns beim Verbrauch fossiler Brennstoffe zu einem grundlegenden Umsteuern.

Eine kluge Kreislaufwirtschaft verbindet Klimaschutz und Rohstoffeffizienz mit einer innovativen und prosperierenden Wirtschaft. In ihr steckt gewaltiges Potential. Um es auszuschöpfen, bedarf es gemeinsamer Anstrengungen in Wissenschaft und Wirtschaft, Gesellschaft und Politik. Nachhaltigkeit ist eine zentrale Forderung, die uns in allen Lebensbereichen betrifft.

Das TUM-Symposium Circular Economy im Juni 2021 leistete dazu einen wertvollen Beitrag. Hochkarätige Wissenschaftlerinnen und Wissenschaftler stellten ihre Forschungen vor, diskutierten Möglichkeiten für Kreislaufprozesse und entwickelten Handlungsempfehlungen. Sie folgten einem interdisziplinären Ansatz, der Grenzen überwindet und eine umfassende Zusammenschau unterschiedlicher Aspekte ermöglicht.

Auf diesem Symposium konnte die Wissenschaft eindrucksvoll zeigen, was sie für unsere Gesellschaft leistet. In einer Zeit, in der ihre Arbeit – zwar von einer kleinen Minderheit, aber sehr lautstark – in Zweifel gezogen wird, ihre Vertreter sich massiven persönlichen Angriffen ausgesetzt sehen und unser wissenschaftlich fundiertes Bild der Welt von kruden Ideologien infrage gestellt wird, war dies eine klare Demonstration ihres Wertes. Die Wissenschaft hat hier einmal mehr ihre gestaltende Kraft für unsere Zukunft bewiesen. Sehr herzlich danke ich der TU München für die Organisation des Symposiums, den teilnehmenden Wissenschaftlerinnen und Wissenschaftlern und den Herausgebenden des vorliegenden Bandes, der die Ergebnisse der Öffentlichkeit präsentiert.

Er wird bei der Bayerischen Staatsregierung verdiente Aufmerksamkeit finden. Als Bestandteil der Hightech Agenda Bayern hat der Freistaat das Thema Nachhaltigkeit und damit auch eine ressourcenschonende Kreislaufwirtschaft fest im Blick. Schon vor Jahrzehnten führte Bayern Kreislaufprozesse ein, zum Beispiel in der Abfallwirtschaft, und erzielte dabei große Erfolge. Diesen Weg setzen wir in der Gegenwart nachdrücklich und konsequent fort. Dabei vertrauen wir fest auf die Leistungen der Wissenschaft, aber auch auf ein breites Engagement in Wirtschaft und Gesellschaft.

Für die Etablierung einer Kreislaufwirtschaft gibt es viel zu tun. Packen wir es gemeinsam an!

# Dr. Florian Herrmann, MdL

Leiter der Bayerischen Staatskanzlei
Staatsminister für Bundesangelegenheiten und Medien
Head of the Bavarian State Chancellery
Minister of State for Federal Affairs and Media

# Sustainability – Circular Economy as a Political Program

Our world now faces formidable challenges – and that even before the appalling war in Ukraine began. If humanity is to survive, it must succeed in decoupling the exponential growth of science, technology and the economy, which has brought us such prosperity and security over the past two centuries, from the equally exponential increase in our consumption of natural resources. Where raw materials and energy are concerned, this is a matter of accelerating development into an upward curve that will flow into a circular economy in harmony with the processes of nature. Our energy supply serves as a particularly urgent example of this dilemma, with climate change forcing us to fundamentally rethink our consumption of fossil fuels.

An intelligent circular economy unites climate protection and raw material efficiency with an innovative and prosperous economy. Such an economy harbors enormous potential – tapping it will require the concerted efforts of science and industry, society and politics. Sustainability is a primary objective affecting all areas of our lives.

The TUM Symposium Circular Economy in June 2021 made an invaluable contribution to this effort. World-class scientists presented their research, discussed opportunities for circular processes, and developed recommendations for action. The symposium adopted an interdisciplinary approach that transcends boundaries to enable a wide-ranging review of differing perspectives.

The symposium afforded science the opportunity to vividly illustrate its value to our society. At a time when the work of science is being called into question – by a small, albeit vocal, minority – when its representatives face severe personal attacks, and when our scientifically based understanding of the world is being challenged by crude ideologies, this event was a forceful demonstration of its worth. Here, science proved, once again, its power to shape our future. I would like to express my sincere gratitude to the Technical University of Munich for organizing the symposium, to the participating scientists and, finally, to the editors of this volume for making the outcome available to the public.

This volume will receive due attention from the Bavarian state government. As part of its high-tech agenda, the State of Bavaria has its sights firmly set on the issue of sustainability and with it a circular economy that will conserve our natural resources. Decades ago, Bavaria introduced closed-loop processes in waste management, for example, with resounding success, and we continue to pursue this strategy today with determination and consistency. In doing so, we place our trust in the achievements of science and in the wide-ranging involvement of industry and society.

There is much to be done to reach the goal of a circular economy. Let us work together to make it happen!

# Nachhaltigkeit als strategisches Ziel der Technischen Universität München

Seit vielen Jahren forschen und lehren wir an der TUM zu unterschiedlichen Facetten des großen Themenspektrums der Nachhaltigkeit. Wir haben ambitionierte strategische Partnerschaften und Allianzen begonnen und können auf ein vielfältiges Engagement und die große Motivation der TUM Community zählen. Es ist nun aber an der Zeit, Nachhaltigkeit als strategisches Thema unserer Universität auf die nächste Stufe zu stellen. Dies hat das Präsidium mit der Einrichtung einer Taskforce Nachhaltigkeit und unserer Stabsstelle, dem TUM Sustainability Office, Anfang 2020 begonnen und wir beschreiten diesen Weg konsequent weiter.

Unsere Vision: Mit Verantwortung, Talenten sowie wissenschaftlicher und technologischer Exzellenz übernehmen wir eine führende Rolle in der nachhaltigen Transformation der Gesellschaft, um Wohlstand im Einklang mit Natur und Umwelt zu ermöglichen.

Unsere Mission: Als weltweit vernetztes Reallabor für transformatives Handeln stellen wir die nachhaltige Entwicklung in den Mittelpunkt unserer Identität und unserer Aktivitäten, indem wir:

- Studierende, Mitarbeitende, Forschende und Lehrende befähigen und vernetzen, um transformative Lösungen für eine nachhaltige Zukunft zu entwickeln;
- Forschung fördern, die das Verständnis der Auswirkungen von Bedingungen und Prozessen auf die Nachhaltigkeit verbessert und den ökologischen Fußabdruck durch verantwortungsvolle Innovationen verringert;
- nachhaltiges Entrepreneurship fördern;
- einen Beitrag zur Entwicklung einer nachhaltigen Wissensgesellschaft leisten;
- die Umgestaltung unserer eigenen physischen, sozialen, wirtschaftlichen und Governance-Systeme fördern.

Inhaltlich beziehen wir uns dabei unter anderem auf die Sustainable Development Goals (SDGs) der Vereinten Nationen. Eines dieser globalen nachhaltigen Entwicklungsziele ist das SDG 12 „Nachhaltige Konsum- und Produktionsmuster sicherstellen“. Die darin implizit und explizit angesprochene Kreislaufwirtschaft ist nicht zuletzt dank des Symposiums, dem dieser Band gewidmet ist, und dem sich immer weiter entwickelnden Netzwerk CirculaTUM ein essenzielles Thema unserer Agenda.

Es geht der TUM jedoch nicht nur darum, Forschung und Lehre in den entsprechenden Themen zu fördern oder uns primär damit zu befassen, wie wir unseren Campus „grüner“ machen. Nur die Integration aller universitären Handlungsfelder wird in einer wirklich nachhaltigeren Universität resultieren. Für die Entwicklung unserer Nachhaltigkeitsstrategie verfolgen wir daher einen „whole institution approach“, also einen ganzheitlichen Ansatz, der unser gesamtes Tun umfasst und integriert.

Gemeinsam mit der Universitätsgemeinschaft wollen wir uns in allen Bereichen konkrete Ziele setzen, Kennzahlen zur Messung unseres Fortschritts formulieren und Maßnahmen umsetzen. Das gemeinsame Vorgehen ist hier von besonderer Bedeutung, denn nur, wenn es uns gelingt eine Kultur der Nachhaltigkeit zu etablieren, können wir wirklich erfolgreich sein. Das Ziel der Umsetzung unserer Strategie ist klar: Unsere positive Wirkung für Mensch, Gesellschaft und Natur soll global und generationenübergreifend nachhaltig sein.

# Professor
# Dr. Gerhard Kramer

Vizepräsident Forschung & Innovation
Technische Universität München
Senior Vice President Research & Innovation
Technical University of Munich


# Sustainability as a Strategic Goal of Technical University of Munich

For many years, TUM's research and teaching has included numerous different facets of sustainability. We have developed ambitious strategic partnerships and alliances and can count on the broad engagement and great motivation of the TUM community. However, it is now time to take sustainability to the next level as a strategic issue. This is what the TUM Board of Management started by establishing a Sustainability Taskforce and the TUM Sustainability Office in 2020. Since then, we are consistently continuing along this path.

Our vision: Through responsibility, talent, scientific and technological excellence, we take a leading role in the sustainable transformation of society to promote prosperity in accordance with nature and the environment.

Our mission: As a globally connected, living laboratory for transformative action, we make sustainable development central to our identity and activities. We do this by:

- enabling and connecting students, staff and faculty to develop transformative solutions for a sustainable future;
- facilitating research that advances the understanding of conditions and processes which impact sustainability, and that reduces ecological footprints through responsible innovation;
- fostering sustainable entrepreneurship;
- contributing to the development of a sustainable knowledge society;
- driving the transformation of our own physical, social, economic and governance systems.

In terms of content, we refer to the Sustainable Development Goals (SDGs) of the United Nations, among others. One of these global goals is SDG 12, “Sustainable Consumption and Production”, in which circular economy is implicitly and explicitly addressed, and which is an essential topic for us. It is part of our agenda, not only because of the symposium to which this volume is dedicated, but also due to the ever-growing CirculaTUM network.

However, TUM is not just concerned about promoting research and teaching, or on how to make our campus “greener”. Only by integrating all university action fields will we realize a university that is truly more sustainable. To develop our sustainability strategy, we are therefore taking a “whole institution approach” that encompasses and integrates all that we do.

Together with the university community, we aim to set specific goals in all areas, formulate metrics to measure our progress, and implement actions. A collaborative approach is particularly important because we can only be truly successful if we establish a culture of sustainability at our university. The goal of implementing our strategy is clear: Our positive impact on people, society and nature should be sustainable both globally and across generations.

# Zirkularität als Prinzip

Die Zirkularität ist dem Mediziner ein vertrautes Prinzip. Ohne funktionierenden Blutkreislauf kann der menschliche Körper nicht leben. Ausgehend hiervon stellt sich die Frage, inwieweit Circular Economy als Herzstück künftiger Wirtschaft unserem Globus, welcher ein nahezu unendlich kleiner Teil im vergänglichen Kosmos ist, eine nachhaltig gesunde Zukunft sichern kann. Für den sterblichen Menschen besteht die Hoffnung darin, dass er nach seinem Tod als eine seelische und stoffliche Entität in einen uns unbekannten ewigen Kreislauf eingehen darf. Im Unterschied hierzu ist Circular Economy eine hochdimensionale Versprechung an die jetzt existierende Welt und die globalen Gesellschaften, die in Folge von Misswirtschaft vor riesigen Problemen stehen. Wie der vorliegende Band zeigt, bietet Circular Economy optimistische, konkrete Perspektiven. Circular Economy bedeutet einerseits das Aufgeben des Lebensstils des stetigen Wachstums, des unachtsamen Verbrauchens und Wegwerfens, des Generierens toxischer Abfälle und andererseits das technologiebasierte Re-Integrieren von verbrauchten Materialien in die Produktion, das gemeinsame Nutzen von Gütern, etc. Alles dieses bedarf durchdachter und anwendungsorientierter Grundlagen aus Natur-, Ingenieur-, Public Health-, Wirtschafts-, Sozial- und Politikwissenschaften. Der eigentliche Erprobungsfall ist jedoch die Wirtschaft und das Unternehmertum selbst, die – wie wir heute schon beobachten können – in Nachhaltigkeit investieren, um damit Geld zu verdienen.

Blicken wir auf Circular Economy, den Gegenstand dieses neuen und weiteren von der TUM Senior Excellence Faculty und ihrem TUM Forum Sustainability verantworteten Bandes, scheint mir das Gedankengut des Wirtschaft-Nobelpreisträgers 2014, Jean Tirole besonders beachtenswert zu sein. Mit seinem Buch „Economics for the Common Good“ steht Jean Tirole nach meinem Verständnis in einer intellektuellen Tradition, die den älteren akademisch ausgebildeten Menschen der modernen westlichen Gesellschaften nicht unbekannt ist.

Auf dem Summit des „Nobel Sustainabilty Trusts“ am 30. November 2021 in Bergen, Norwegen, hatte ich die Gelegenheit, Jean Tirole zu hören. Er setzt auf eine umfassende soziale Verantwortlichkeit (Comprehensive Social Responsibility). Aus seiner Sicht liegt hier die große Herausforderung und Verpflichtung der internationalen Wirtschaftsunternehmen und Stakeholder. Auf dem erwähnten Summit wurde von Teilnehmenden aus der internationalen Wirtschaft unterstrichen, dass heute der ganze Bereich des „Financing“, will er im Finanzieren und Anschieben von Wirtschaftsprojekten erfolgreich sein, nicht mehr ohne Betrachtungen und Analysen zur Nachhaltigkeit auskommen kann. Diese Entwicklung wundert nicht angesichts der Tatsache, dass weltweit viele Menschen verschiedenster Kulturen die Bedrohung des Klimawandels und abnehmender Bio-Diversität spüren und verstehen.

Möge vorliegendes Buch zu Circular Economy den Leserinnen und Lesern aus Wissenschaft, Wirtschaft, Administration und Politik, insbesondere auch den jungen Menschen eine Anregung und weitere Ideen-Quelle beim Blick auf nachhaltiges und vernünftiges Wirtschaften sein!

# Professor Dr. Michael Molls

Sprecher der Senior Excellence Faculty
Direktor des Institute for Advanced Study
Technische Universität München
Speaker of the Senior Excellence Faculty
Director of the Institute for Advanced Study
Technical University of Munich

# Circularity as a Prinicple

Circularity is a familiar principle to the medical profession. After all, the human body could not remain alive without functioning blood circulation. This poses the analogous question to what extent a circular economy, as the heart of a future economy, can ensure a sustainably healthy future for our globe, an almost infinitesimally small part of a transient cosmos. Human mortals hold onto the hope that, after death, they may become a spiritual and material entity in an eternal cycle yet unknown to us. Circular economy, however, is a lofty promise to the present-day world and to the global societies now facing daunting problems as a result of mismanagement. As this volume shows, circular economy holds optimistic, concrete prospects for betterment. On the one hand, it will mean renouncing the idea of unlimited growth, changing our lifestyle of heedless consumption and throw-away culture, stopping the generation of toxic waste; on the other, it will mean, among other things, the technology-based re-integration of used materials into production and the sharing of goods. All of this requires well-conceived and application-oriented foundations in the natural sciences, engineering, public health, economics, social and political sciences. Yet the real test case will be the economy and entrepreneurship itself, which – as we can already observe today – invest in sustainability for profit's sake.

No discussion of circular economy, a wide-ranging dialogue to which this volume by the TUM Senior Excellence Faculty and its TUM Forum Sustainability contributes, can leave unconsidered the formative ideas of Jean Tirole, the 2014 Nobel Laureate in Economics. His book Economics for the Common Good is grounded in an intellectual tradition not unfamiliar to an older generation of academics in modern western societies.

I had the opportunity to hear Jean Tirole speak at the Nobel Sustainability Trust Summit in Bergen, Norway, on 30 November 2021. His approach emphasizes comprehensive social responsibility. In his view, this is where the major challenges and obligations of international businesses and stakeholders lie. At this summit, participants from the international business community emphasized that the entire field of "financing" can no longer afford to neglect considerations of sustainability if it wants to be successful in financing and initiating business projects. This development is not surprising in view of the fact that many people from different cultures around the world feel and understand the threat of climate change and declining biodiversity.

May the present volume on circular economy be a source of inspiration and ideas for readers, particularly those of the younger generation, working in the fields of science, business, administration, and politics!

# Symposium Kreislaufwirtschaft

# Symposium Circular Economy

# Einleitung
# Introduction

**Prof. Dr. Dr. h.c. Ralf Reichwald**
TUM Senior Excellence Faculty; Honorary Senator of the TU Freiberg; Professor of Business Administration – Leipzig Graduate School of Management (HHL); Professor of Business Administration – Information, Organization and Management, TUM

**Prof. Dr.-Ing. Drs. h.c. Peter Wilderer**
TUM Senior Excellence Faculty; Founder of the Institute for Earth System Preservation (IESP); Stockholm Water Prize (2003); Professor for Water Quality and Waste Management, TUM

# Das Online-Symposium „Circular Economy“ im Dahlem-Format

# The Online-Symposium “Circular Economy” in Dahlem-Format

Das TUM-Symposium zur Circular Economy sollte ursprünglich nach dem „Dahlem-Konferenzformat“ als 3-tägige Fach-Konferenz im TUM-Akademiezentrum Raitenhaslach durchgeführt werden. Aufgrund der Corona-Restriktionen fanden die Vorbereitungen und das Symposium in mehreren Schritten in einer modifizierten Form des Dahlem-Formats als Online-Konferenz statt.

The TUM Symposium on the Circular Economy was originally planned to be held according to the „Dahlem Conference Format“ as a 3-day specialist conference at the TUM Academy Center Raitenhaslach. Due to Corona restrictions, the preparations and the symposium took place in several steps in a modified form of the Dahlem format as an online conference.

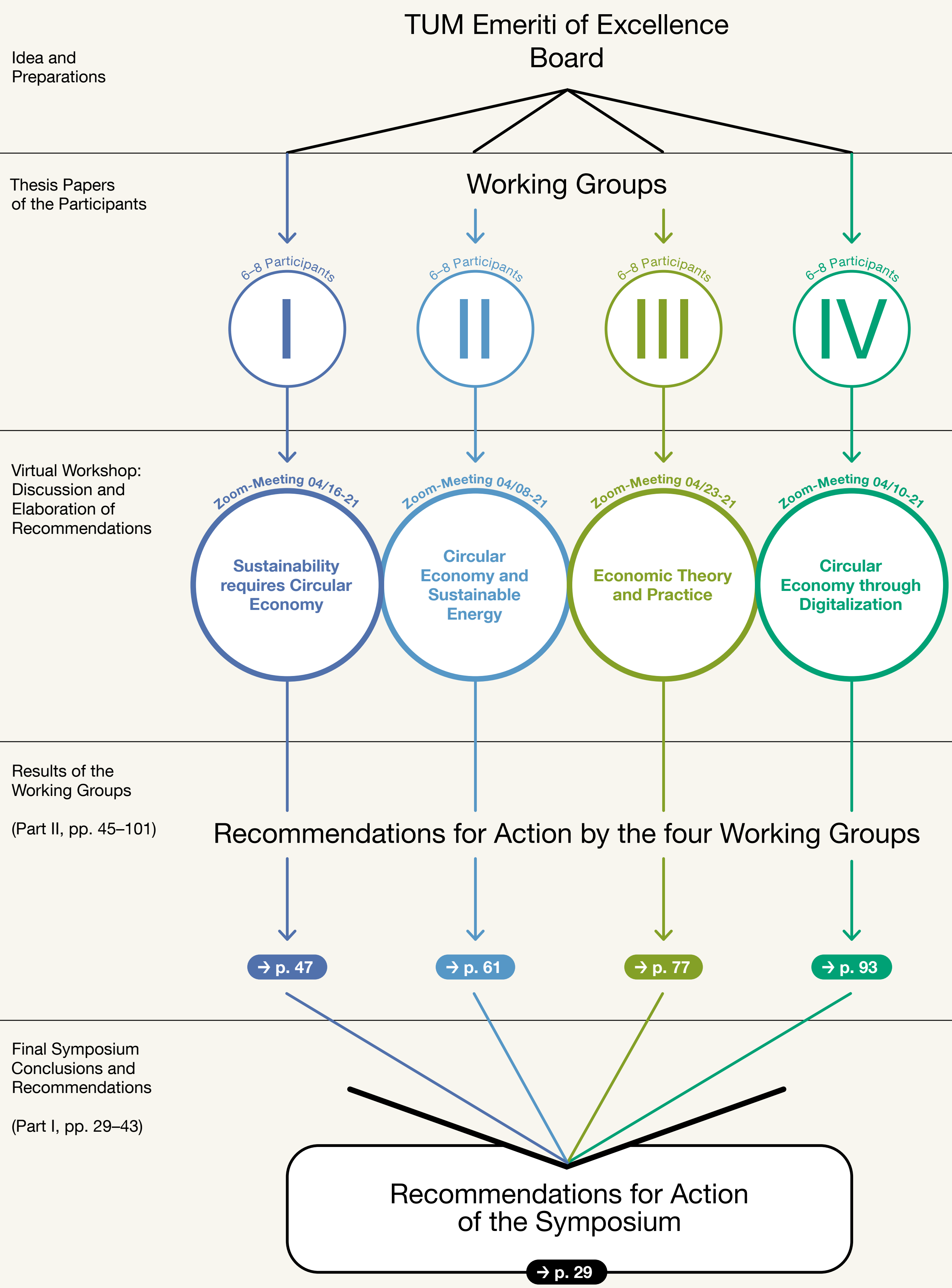


Figure 1: Conference “Circular Economy” according to Dahlem format (modified) as online conference

# Das Online-Symposium „Circular Economy“ im Dahlem-Format

Entstanden ist das Dahlem-Konferenzformat im Jahr 1974 in der Absicht, parallel zu den üblichen Konferenzen und Poster-Sessions, einen wissenschaftlichen Diskurs durchzuführen, bei dem nicht nur das Erreichte, sondern viel mehr die Wissenslücken herausgearbeitet werden, die in der Folge zu innovativen Forschungsthemen führen.

Überaus großzügig finanziert wurden Dahlem-Konferenzen bis 1989 vom Stifterverband der Deutschen Wissenschaft und vom Berliner Senat. Da sich dieses Konferenzformat in zahlreichen Konferenzen bewährt hatte, schlug Berlin vor, in Würdigung der langjährigen Tradition und Reputation des Berliner Bezirks „Dahlem“ in Wissenschaft und Kunst diesem Konferenzschema die Bezeichnung „Dahlem-Konferenzen“ zu geben. Das Konferenzformat wurde unter diesem Namen patentiert. Danach wurden Dahlem-Konferenzen bis 2012 durch die Freie Universität Berlin in Kooperation mit der Ludwig-Maximilians-Universität München sowie danach unter anderem Namen durch das Frankfurt Institute for Advanced Studies weitergeführt.

**Das Online-Symposium „Circular Economy“ nach dem Dahlem-Konferenzformat zeichnet sich durch die folgenden Merkmale aus:**

**← vgl. Abbildung 1, Seite 25**

- Bei diesem Konferenzformat nehmen eine **begrenzte Anzahl eingeladener Personen** an den Veranstaltungen teil. In unserem Fall wurden 39 Personen eingeladen, ausgewiesene Experten aus der Wissenschaft und Experten aus der Praxis.
- Es wurden **Arbeitsgruppen zu 4 Themenschwerpunkten** der Circular Economy gebildet (Abbildung), so dass das gesamte Themenfeld aus unterschiedlichen disziplinären Blickrichtungen beleuchtet wurde. Alle Arbeitsgruppen wurden von 2, bzw. von 3 **Moderatoren** (sog. Chairs) begleitet.
- Die Vorbereitungen zum Symposium fanden in **mehreren Konferenzschritten** statt.
- Im **ersten Schritt** wurden alle Teilnehmer verpflichtet, ein Thesenpapier (1–2 Seiten) zu dem jeweiligen Themenschwerpunkt zur Diskussion zu stellen.
- Die Thesenpapiere waren die Grundlage für den **zweiten Schritt**: Im April 2021 fand dazu für jede Arbeitsgruppe ein Online-Workshop statt, in dem die Thesenpiere der Teilnehmer diskutiert und die Ergebnisse zu Kernaussagen verdichtet wurden.
- Im **dritten Konferenzschritt**, dem Online-Symposium am 11. Juni 2021, wurden die Kernaussagen der Arbeitsgruppen von den Chairs vorgetragen und mit allen Teilnehmern diskutiert. Die **Kernaussagen der vier Arbeitsgruppen** wurden schließlich in einem weiteren Schritt zu übergreifenden Empfehlungen verdichtet und dem Plenum zur Diskussion vorgestellt.
- Ziel des Symposiums war die **Verabschiedung der erarbeiteten Empfehlungen** als Handlungsempfehlungen für Entscheider in der Wirtschaft, Politik und Wissenschaft.
- Als **Nachbearbeitung zum Symposium** wurden alle Teilnehmer aufgefordert, Ihre Thesenpapiere, die Kernaussagen und Schlussfolgerungen zu überprüfen und ggf. zu verbessern oder zu ergänzen.

# The Online-Symposium "Circular Economy" in Dahlem-Format

The Dahlem Conference Format originated in 1974 with the intention of holding a scientific discourse parallel to the usual conferences and poster sessions, in which not only achievements, but much more gaps in knowledge are identified, which subsequently may trigger innovative research topics.

Generous funding for Dahlem Conferences was provided by the Donors' Association for the Promotion of Sciences and Humanities in Germany and the Berlin Senate until 1989. Since this conference format had proven its worth in numerous conferences, Berlin proposed to give this conference format the name "Dahlem Conferences" in appreciation of the long-standing tradition and reputation of the Berlin district "Dahlem" in science and art. The conference format was patented under this name. Thereafter, Dahlem Conferences were continued by Freie Universität Berlin in cooperation with Ludwig-Maximilians-Universität München until 2012, and then by the Frankfurt Institute for Advanced Studies under a different name.

**The online symposium "Circular Economy" following the Dahlem Conference Format is characterized by the following features:**

← **Figure 1, page 25**

- In this conference format, a **limited number of invited people** attend the events. In our case, 39 people were invited, both proven experts from science and experts from practice.
- **Working groups were formed on 4 main topics** of the Circular Economy (Figure), so that the entire topic area was examined from different disciplinary perspectives. All working groups were accompanied by 2 or 3 **moderators** (so-called chairs).
- The preparations for the symposium took place in **several conference steps**.
- In the **first step**, all participants were required to submit a position paper (1–2 pages) on the respective topic for discussion.
- The various position papers were the basis for the **second step**: In April 2021, an online workshop was held for each working group, in which the participants' position papers were discussed and the results condensed into key statements.
- In the **third conference step**, the online symposium on June 11, 2021, the core statements of the working groups were presented by the chairs and discussed with all participants. In a further step, the **core statements of the four working groups** were condensed into overarching statements and presented to the plenum for discussion.
- The aim of the symposium was to **adopt the statements as recommendations** for action for decision-makers in business, politics and science.
- As a **follow-up to the symposium**, all participants were asked to review their position papers, the key statements and conclusions and, if necessary, to improve or supplement them.

# Part I

## Handlungs-empfehlungen des Symposiums

## Recommendations for Action of the Symposium

**Prof. Dr. Magnus Fröhling**
Professor of Circular Economy,
Campus Straubing for Biotechnology and Sustainability, TUM

# I.1. Grundlegendes Verständnis der Kreislaufwirtschaft

Die Kreislaufwirtschaft (Circular Economy, CE) zielt darauf ab, Nachhaltigkeitsziele, wie die UN-Ziele für nachhaltige Entwicklung (Sustainable Development Goals, SDGs) und das Pariser Übereinkommen zum Klimaschutz, zu erreichen. Dabei basiert die Kreislaufwirtschaft auf der Vision von geschlossenen Stoff- und Produktkreisläufen, die durch erneuerbare Energien angetrieben werden. Sie ist in ein Wirtschaftssystem einzubetten, in dem auf nachhaltige Weise Werte geschaffen und erhalten werden. Zur Erreichung dieser Ziele bedarf es einer Systemperspektive, die Systeme auf der Mikro-, Meso- und Makroebene betrachtet. Indem wir, die Teilnehmerinnen und Teilnehmer des TUM Forum Sustainability – Circular Economy, die einzelnen Akteure in den Systemen, ihre Beziehungen und das System als Ganzes analysieren, wollen wir Empfehlungen für Entscheidungsträger in politischen Gremien, Unternehmen und Forschungseinrichtungen für die notwendigen Entwicklungen formulieren. So möchten wir dazu beitragen, die Potenziale der Kreislaufwirtschaft freizusetzen und zu nutzen.

## Anmerkung

**Unser Verständnis von Kreislaufwirtschaft ist nahe an der Definition von Kirchherr et al. (2017):**

„Kreislaufwirtschaft beschreibt ein Wirtschaftssystem, das auf Geschäftsmodellen basiert, die das Konzept eines Lebensendes von Materialien, Produkten und Dienstleistungen in Produktions-/Distibutions- und Konsumprozessen durch Vermeidung, Wiederverwendung, Aufarbeitung und Recycling ersetzt. Dies findet auf der Mikroebene (Produkte, Unternehmen, Verbraucher), der Mesoebene (Öko-Industrielle Parks) und der Makroebene (Stadt, Region, Nation mit dem entsprechenden politischen Umfeld) statt, um so eine nachhaltige Entwicklung in Bezug auf Umweltqualität, wirtschaftlichem Wohlstand und sozialer Gerechtigkeit zum Nutzen heutiger und künftiger Generationen zu erreichen.“

# I.1. Basic Understanding of Circular Economy

The Circular Economy (CE) strives to contribute to achieving sustainability goals such as the UN Sustainable Development Goals (SDGs) and the Paris Agreement. Thereby, CE is based on the vision of closed resource and product cycles powered by renewable energy and is embedded in an economic system where values are created and maintained in a sustainable way. Achieving these goals requires a systems perspective, considering systems on the micro, meso and macro level. Analysing single actors in the systems, their relationships, and the system as a whole, we – the participants of the TUM Forum Sustainability – Circular Economy, formulate recommenndations to decision makers in policy-making bodies, businesses, and research institutions for the needed developments to unleash the potentials of CE.

## Annotation

**Our Understanding of CE is close to the Definition of Kirchherr et al. (2017):**

"A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations."

Das Jahr 2021 war durch eine anhaltende Pandemiesituation und Extremwetterereignisse gekennzeichnet. Sowohl die Klimaerwärmung als auch Extremwetterereignisse können – mit immer größerer Sicherheit – auf die Auswirkungen des anthropogenen Klimawandels zurückgeführt werden (IPBES 2020 und IPCC 2021). Die globale Erwärmung von 1,1°C durch menschliche Einflüsse und die erwartete weitere Emissionsentwicklung wurden u.a. von der Klimakonferenz in Glasgow anerkannt, die in ihrer Abschlusserklärung diesbezüglich „Alarm und äußerste Besorgnis“ zum Ausdruck brachte und die Dringlichkeit verstärkter Klimaschutzbemühungen und -maßnahmen betonte (UNFCC, 2021). Die Eindämmung des anthropogenen Klimawandels muss jedoch parallel zu und im Kontext weiterer nachhaltiger Entwicklungsziele auf globaler, nationaler und regionaler Ebene angegangen werden, wie die jüngsten und laufenden Diskussionen z. B. über den Kohleausstieg mit Entwicklungs- und Schwellenländern, aber auch in Deutschland gezeigt haben. Insofern besteht ein dringender Bedarf an umfassenden Ansätzen, die eine nachhaltige Entwicklung im Sinne der Brundtlandt-Kommission (WCED 1987) ermöglichen und die in der Agenda 2030 für nachhaltige Entwicklung der Vereinten Nationen (UN 2015) festgelegten Ziele für nachhaltige Entwicklung erreichen.

Einen Ansatz, der das Potenzial hat, wesentlich zur Erfüllung dieser Anforderungen beizutragen, ist die sogenannte Kreislaufwirtschaft (Circular Economy, CE). Die Kreislaufwirtschaft will zur Erreichung von Nachhaltigkeitszielen wie den Nachhaltigen Entwicklungszielen der UN (Sustainable Development Goals, SDGs) und dem Pariser Übereinkommen zum Klimaschutz beitragen. Dabei basiert die Kreislaufwirtschaft auf der Vision geschlossener Stoff- und Produktkreisläufe, die durch erneuerbare Energien angetrieben werden. Sie ist dabei eingebettet in ein Wirtschaftssystem, in dem Werte auf nachhaltige Weise geschaffen und erhalten werden. So sollen Umweltentlastungen, wirtschaftlicher Wohlstand und positive soziale Auswirkungen erreicht werden (vgl. CEID 2021b). Hierzu wird eine Systemperspektive eingenommen, die die Mikro-, Meso- und Makroebene berücksichtigt. Analysiert werden die einzelnen Akteure in den Systemen, ihre Beziehungen und das System als Ganzes. Dieser umfassende Ansatz hat in den letzten Jahren in Politik, Forschung sowie Wirtschaft und Gesellschaft erhebliche Aufmerksamkeit erlangt. So spielt die Kreislaufwirtschaft weltweit eine zentrale Rolle in der Wirtschafts- und Nachhaltigkeitspolitik, etwa im europäischen Circular Economy Action Plan (EC, 2020) oder dem 14. chinesischen Fünfjahresplan (NPC, 2021). Die Kreislaufwirtschaft stellt zudem ein zentrales und sehr dynamisches Forschungsfeld dar und wird zunehmend von Unternehmen und Privatpersonen aufgegriffen. Dies spiegelt sich auch in nationalen Bestrebungen wie der branchenübergreifenden Circular Economy Initiative Deutschland (CEID, 2021) wider.

Vor diesem Hintergrund war es Ziel des TUM Forum Sustainability zur Kreislaufwirtschaft, Hintergründe, Stand, Anforderungen und Perspektiven der Kreislaufwirtschaft zu analysieren und Handlungsempfehlungen für Politik, Wissenschaft, Bildung und Wirtschaft für die notwendigen Entwicklungen zur Entfaltung der Potenziale der Kreislaufwirtschaft zu formulieren. Um dieses Ziel zu erreichen, erarbeiteten die Teilnehmerinnen und Teilnehmer des Symposiums in einem strukturierten Prozess in Anlehnung an das Dahlem-Konferenzformat (vgl. S. 25) 10+1 Empfehlungen auf der Basis von Thesen, die in Arbeitsgruppen zu spezifischen Aspekten erarbeitet wurden (vgl. S. 44 ff.). Diese 10+1 Empfehlungen werden im folgenden Abschnitt vorgestellt.

The year 2021 has shown an enduring pandemic situation and severe extreme weather events accompanied by a continue in global warming. Both global warming and severe weather events can – with ever increasing further proven certainty – be attributed to the effect of anthropogenic climate change (IPBES 2020 and IPCC 2021). The assumed 1.1°C of human caused global warming and the trajectories of the further emission development were acknowledged by the Glasgow Climate Change Conference which expressed in its final declaration “alarm and utmost concern” in this regard and stressed the urgency of enhancing climate ambition and action (UNFCC, 2021). However, mitigating climate change has to be approached alongside and in the context of further sustainable development goals, on the global, national, and regional scale, as recent and ongoing discussions of e. g., the coal phase out with developing and emerging countries but also in Germany have shown. There is an urgent need for comprehensive approaches facilitating a sustainable development complying with the Brundlandt’s Commission understanding (WCED 1987) and achieving the Sustainable Development Goals set in the United Nations’ 2030 Agenda for Sustainable Development (UN 2015).

One approach which has the potential to fulfil these requirements is the so-called Circular Economy (CE). The Circular Economy strives to contribute to achieving sustainability goals such as the Sustainable Development Goals (SDGs) and the Paris Agreement. Thereby, CE is based on the vision of closed resource and product cycles powered by renewable energy and is embedded in an economic system where values are created and maintained in a sustainable way. Thus, environmental reliefs, economic prosperity and positive social impacts shall be achieved (cf. CEID 2021b). To reach these goals, a systems perspective is taken, considering the micro, meso and macro level. Single actors in the systems, their relationships, and the system as a whole are analyzed. Forming such a comprehensive approach, the CE has gained considerable attention in the last years in politics, research as well as industry and society. CE plays a central role in economic and sustainability policies worldwide, e. g., the European Circular Economy Action Plan (EC, 2020), the 14th Chinese Five Year Plan (NPC, 2021) and others, constitutes a central and bustling research field and is more and more taken up by businesses and individuals. These international developments are also reflected in national endeavors like the cross-sector Circular Economy Initiative Deutschland (CEID, 2021).

Against this backdrop, it was aim of the TUM Forum Sustainability on Circular Economy to analyze background, status, requirements and prospects of CE and formulate recommendations for action for politics, science, education and economy for the needed developments to unleash the potentials of CE. In order to achieve this aim the participants of the symposium elaborated in a structured process following Dahlem format (cf. p. 25) finally 10+1 recommendations on the basis of recommendations eleaborated by working groups focusing on specific aspects (cf. pp. 44). These 10+1 recommendations are presented in the following section.

# I.2. Handlungsempfehlungen des Symposiums

**1**

**Die Ziele für eine Kreislaufwirtschaft sollten von Stakeholdern aus Politik, Wissenschaft, Wirtschaft und Gesellschaft aus gesamtgesellschaftlichen Nachhaltigkeitszielen abgeleitet werden.**

**2**

**Damit die Transformation hin zu einer nachhaltigen Kreislaufwirtschaft gelingt, sollten die Anstrengungen der Stakeholder zur Erreichung dieser Ziele in einem vernetzten Handlungsrahmen und in kollaborativer Weise erfolgen.**

**3**

**Der politische, wirtschaftliche und technologische Rahmen für eine Kreislaufwirtschaft muss so gestaltet werden, dass die Kraft der Marktwirtschaft ihr Potenzial zur Unterstützung der Entwicklung nachhaltiger und innovativer Unternehmen und Technologien entfalten kann.**

**4**

**Unternehmen müssen gemeinsam mit ihren Kunden und weiteren Stakeholdern neue kreislauforientierte Geschäftsmodelle entwickeln und bewerten, um eine nachhaltige Wertschöpfung zu ermöglichen.**

**5**

**Um den Energiebedarf einer Kreislaufwirtschaft zu decken, sollte das langfristige Ziel für Deutschland und den überwiegenden Teil der Welt sein, eine vollständig nachhaltige Energieversorgung zu erreichen. Dies erfordert sowohl die Entwicklung effizienter Technologien als auch den Einsatz von Brückentechnologien.**

**6**

**Die Nachhaltigkeitsziele in Bezug auf Kreislaufwirtschaft und Energie sind nur global realisierbar. Mögliche Konflikte zwischen der lokalen, regionalen und globalen Ebene müssen gelöst werden. Dies gilt für die Energieversorgung, aber auch für den Import und Export von Ressourcen, Altprodukten und Abfällen.**

**7**

**Wir brauchen eine leistungsfähige digitale Infrastruktur und einen hohen Digitalisierungsgrad, der insbesondere im öffentlichen Sektor und im Mittelstand in Deutschland weiter vorangetrieben werden muss.**

**8**

**Neben etablierten IT-Werkzeugen sollten neue, vielversprechende Technologien wie Blockchain und Künstliche Intelligenz (KI) eingesetzt, erprobt und weiterentwickelt werden.**

**9**

**Neue quantitative Methoden für eine ganzheitliche Nachhaltigkeitsbewertung von kreislaufwirtschaftlichen Lösungen sind notwendig, um negative Effekte durch einseitige Priorisierung zu vermeiden und die Anstrengungen auf wirklich nachhaltige Lösungen zu fokussieren.**

**10**

**Wir brauchen maßgeschneiderte Kommunikationsinstrumente für Märkte und Kunden, um das gesellschaftliche Vertrauen und die Unterstützung für die Verbreitung von Lösungen für die Kreislaufwirtschaft zu erleichtern.**

**All diese 10 Botschaften und Empfehlungen müssen in Lehrpläne und Ausbildungsprogramme integriert werden, um Kreislaufwirtschaft in Theorie und Praxis zu implementieren und den Übergang zur Nachhaltigkeit im weiteren Sinne zu beschleunigen. Lehre und Ausbildung auf allen Ebenen (frühkindliche Bildung, Schule, Handwerk, Hochschule, lebenslanges Lernen) sind erforderlich.**

# I.2. Recommendations for Action of the Symposium

**1**

**Actors from politics, science, industry, and society (stakeholders) should derive the goals for a Circular Economy (CE) from overall societal sustainability goals.**

**2**

**For the successful transformation towards a sustainable CE, stakeholder efforts (to achieve these goals) should be taken jointly in an intertwined network of action and in a collaborative manner.**

**3**

**The political, economic, and technological framework for a CE has to be designed in a way that the power of the market economy can unleash its potential to support the development of sustainable and innovative businesses and technologies.**

**4**

**Businesses need to develop and evaluate new circular business models together with their customers and stakeholders in order to facilitate sustainable value creation.**

**5**

**To fulfill the energy demand in a Circular Economy, the long-term goal for Germany and the major part of the world should be to achieve a complete sustainable energy supply. This requires the development of efficient technologies as well as the use of transition technologies.**

**6**

**The sustainability goals regarding CE and energy are only attainable on a global scale. Potential conflicts between the local, regional, and global level have to be resolved. This holds for energy supply but also import and export of resources, used products and waste.**

**7**

**We need a powerful digital infrastructure and a high grade of digitalization, which has to be further promoted, especially in the public sector and in small and mid-sized enterprises (SME) in Germany.**

**8**

**Besides established IT-tools, new promising technologies such as blockchain and artificial intelligence (AI) should be applied, tested, and developed.**

**9**

**New quantitative methods are needed for a holistic sustainability assessment of CE solutions to prevent negative effects caused by one-sided prioritization and focus efforts to truly sustainable solutions.**

**10**

**We need tailored communication instruments for markets and customers to facilitate societal trust and support for the dissemination of CE solutions.**

**All these 10 messages and recommendations need to be integrated into curricula and training programs to deploy Circular Economy into theory and practice and accelerate the broader sustainability transition. Teaching and training at all levels (early childhood education, school, craft, college, lifelong learning) are required.**

# I.3. Erläuterungen

**1**

**Die Ziele für eine Kreislaufwirtschaft sollten von Stakeholdern aus Politik, Wissenschaft, Wirtschaft und Gesellschaft aus gesamtgesellschaftlichen Nachhaltigkeitszielen abgeleitet werden.**

Das Erreichen von Nachhaltigkeitszielen ist ein multikriterielles Problem. Einzelne Ziele können hierbei in Konflikt zueinander stehen. Dies gilt auch für die Kreislaufwirtschaft, bei der z. B. die Schließung von Stoffkreisläufen und die Vermeidung von Abfällen zu einem höheren Energieeinsatz und/oder höheren Treibhausgasemissionen führen können. Es ist daher von zentraler Bedeutung, dass die Kreislaufwirtschaft nicht als Selbstzweck gesehen wird, sondern dass ihre Etablierung mit den übergeordneten Nachhaltigkeitszielen von Wissenschaft und Politik in Einklang gebracht wird. Da die Akzeptanz durch alle Beteiligten entscheidend ist, müssen die gewählten Ziele und Prioritäten auf einem gesellschaftlichen Konsens beruhen.

**2**

**Damit die Transformation hin zu einer nachhaltigen Kreislaufwirtschaft gelingt, sollten die Anstrengungen der Stakeholder zur Erreichung dieser Ziele in einem vernetzten Handlungsrahmen und in kollaborativer Weise erfolgen.**

Kreislaufwirtschaft kann nur dann erfolgreich sein und ihr ganzes Potenzial entfalten, wenn sie von allen Beteiligten – Gesellschaft, Industrie, Wissenschaft und Politik – vorangetrieben wird. Um wirklich nachhaltige Lösungen zu erreichen und lokale Optima zu vermeiden, sollten die Stakeholder kollaborativ und in einem konzertierten Ansatz zusammenarbeiten.

**3**

**Der politische, wirtschaftliche und technologische Rahmen für eine Kreislaufwirtschaft muss so gestaltet werden, dass die Kraft der Marktwirtschaft ihr Potenzial zur Unterstützung der Entwicklung nachhaltiger und innovativer Unternehmen und Technologien entfalten kann.**

Die Kreislaufwirtschaft sollte menschenzentriert angegangen werden und sich auf einzelne Akteure in Gesellschaft, Wirtschaft, Wissenschaft oder Politik konzentrieren. Damit die Kreislaufwirtschaft erfolgreich werden kann, ist jedoch ein nachhaltiges Verhalten dieser Akteure notwendig. Daher müssen die politischen, wirtschaftlichen und technologischen Rahmenbedingungen hierfür Anreize schaffen. Politik muss Nachhaltigkeit ganzheitlich angehen, negative Umweltauswirkungen von Einzelpersonen, Unternehmen und öffentlichen Akteuren müssen zu Kosten führen, die von den Verantwortlichen zu tragen sind. Es werden Technologien und Infrastrukturen benötigt, um Kreisläufe zu schließen und praktikable Lösungen umzusetzen. Zudem bedarf es Lösungen, um technologische Lock-ins durch bestehende Infrastrukturen und Industrieanlagen zu überwinden. Eine unvoreingenommene Offenheit für alternative und unkonventionelle Lösungen ist eine Voraussetzung für einen Ideenwettbewerb, der zu nachhaltigen Lösungen führt.

**4**

**Unternehmen müssen gemeinsam mit ihren Kunden und weiteren Stakeholdern neue kreislauforientierte Geschäftsmodelle entwickeln und bewerten, um eine nachhaltige Wertschöpfung zu ermöglichen.**

Der Wandel hin zu einem nachhaltigen Wirtschaftssystem erfordert auch nachhaltige Geschäftsmodelle. Bestehende Geschäftsmodelle basieren oft auf einer linearen Wirtschaftsweise von Entnahme – Herstellung – Nutzung – Entsorgung („Take-Make-Use-Dispose"). Unternehmen müssen diese anpassen oder neue Wege entwickeln, um nachhaltig Werte zu schaffen und sowohl ihre Kunden als auch sich selbst davon profitieren zu lassen. Dies sollte sowohl für Produkte als auch für Dienstleistungen gelten. Es ist wichtig, dass diese neuen Geschäftsmodelle Akzeptanz finden, erfolgreich sind und dass dabei mögliche Problemverschiebungen und Rebound-Effekte vermieden werden. Die Entwicklung dieser Geschäftsmodelle und deren Bewertung sollte daher gemeinsam mit Kunden und weiteren Stakeholdern entlang der gesamten Wertschöpfungskette erfolgen.

# I.3. Explanations

**1**

**Actors from politics, science, industry, and society (stakeholders) should derive the goals for a Circular Economy (CE) from overall societal sustainability goals.**

Achieving sustainability goals is a multi-criteria problem in which conflicts between single objectives may occur. The same holds for the Circular Economy where, e. g., closing of material cycles and eliminating waste may be achieved at the cost of a higher input of energy and/or higher greenhouse gas emissions. It is therefore a key requirement, that CE is not seen as a purpose in itself but that the goals for establishing a Circular Economy are well aligned with superordinate sustainability goals set by science and politics. Since acceptance by all stakeholders is key, it is of central importance that the chosen goals and priorities are based on a societal consensus.

**2**

**For the successful transformation towards a sustainable CE, stakeholder efforts (to achieve these goals) should be taken jointly in an intertwined network of action and in a collaborative manner.**

CE can only be successful and unfold its whole potential when it is driven by all stakeholders, covering society, industry, science and politics. To achieve superior solutions and avoid local optima the stakeholders should work together collaboratively and in a concerted approach.

**3**

**The political, economic, and technological framework for a CE has to be designed in a way that the power of the market economy can unleash its potential to support the development of sustainable and innovative businesses and technologies.**

The circular economy should be approached in a human-centred way and focus on individual actors in society, industry, science or politics. However, in order to make the CE succeed a sustainable behavior of these actors is necessary. Therefore, the overall political, economic and technological framework needs to incentivize this. Policies need to address sustainability in a holistic way. Negative environmental impacts of individuals, business and public actors need to lead to true costs to be borne by those responsible. Technologies and instrastructures are necessary to close loops and infrastructures are needed to implement feasible solutions. Solutions are needed to overcome technological lock-ins through existing infrastructure and industrial installations. An unbiased openness to alternative and unconventional technology solutions is a prerequisite for a competition of ideas, leading to sustainable solutions.

**4**

**Businesses need to develop and evaluate new circular business models together with their customers and stakeholders in order to facilitate sustainable value creation.**

The transformation towards a sustainable economic system demands also for sustainable business models. Existing models are often tied to the linear „take-make-use-dispose“ logic. Businesses need to adapt their current practices or develop new ways to propose value to their customers, deliver it and profit from it. This should cover products as well as services. It is important that these new business models find acceptance and are successful on the one hand and that on the other hand potential problem shifts and rebound effects are avoided. Thus, their development and evaluation should be carried out together with customers and further stakeholders, all along the value chain.

**5**

**Um den Energiebedarf einer Kreislaufwirtschaft zu decken, sollte das langfristige Ziel für Deutschland und den überwiegenden Teil der Welt sein, eine vollständig nachhaltige Energieversorgung zu erreichen. Dies erfordert sowohl die Entwicklung effizienter Technologien als auch den Einsatz von Brückentechnologien.**

Dem zweiten Hauptsatz der Thermodynamik folgend ist jeder Umwandlungsprozess mit einem Verlust an nutzbarer Energie verbunden. Daher ist ein externer Energieinput notwendig, um Materialbereitstellung und -flüsse in einer Kreislaufwirtschaft zu ermöglichen. Damit negative Auswirkungen auf das Klima vermieden werden, muss diese Energie auf nachhaltige Weise bereitgestellt werden. Deshalb sollten Deutschland wie auch der überwiegende Teil der Welt ihr Energiesystem vollständig auf eine nachhaltige Energieversorgung und -verteilung umstellen. Dazu bedarf es Forschung und Entwicklung zu effizienten Technologien. Bis diese auf globaler Ebene eingesetzt werden können, sind möglicherweise Brückentechnologien erforderlich. Diese müssen jedoch im Hinblick auf ihre Notwendigkeit sowie potentiell negative Auswirkungen auf andere Nachhaltigkeitskriterien, die damit verbundenen Risiken und Kosten gründlich diskutiert werden.

**6**

**Die Nachhaltigkeitsziele in Bezug auf Kreislaufwirtschaft und Energie sind nur global realisierbar. Mögliche Konflikte zwischen der lokalen, regionalen und globalen Ebene müssen gelöst werden. Dies gilt für die Energieversorgung, aber auch für den Import und Export von Ressourcen, Altprodukten und Abfällen.**

Die Erreichung der Nachhaltigkeitsziele ist eine globale Aufgabe. Die SDGs sind als globale Agenda für das Jahr 2030 verabschiedet worden. Da wir bereits in einer globalisierten Welt leben und Produkte und Dienstleistungen in vielfältigen, vernetzten und globalen Wertschöpfungsketten hergestellt und an Kunden in aller Welt geliefert werden, muss auch die Kreislauf- und Energiewirtschaft global gedacht werden. Gleichzeitig sind regionale und lokale Lösungen zur Schließung von Stoffkreisläufen oder zur Energieversorgung oft vorzuziehen. Der Export von gebrauchten Produkten und Abfällen in andere Teile der Welt ist aus ökologischer und ethischer Sicht problematisch. Daher müssen der Import und Export von Ressourcen, Altprodukten und Abfällen sowie die Energieversorgung unter Berücksichtigung der drei Ebenen behandelt werden. Potenzielle Zielkonflikte sind bei der Entwicklung nachhaltiger kreislaufwirtschaftlicher Lösungen aufzulösen.

**7**

**Wir brauchen eine leistungsfähige digitale Infrastruktur und einen hohen Digitalisierungsgrad, der insbesondere im öffentlichen Sektor und im Mittelstand in Deutschland weiter vorangetrieben werden muss.**

Die Digitalisierung und die Bereitstellung einer leistungsfähigen digitalen Infrastruktur sind wichtige Voraussetzungen und Triebkräfte für eine Kreislaufwirtschaft. So können z. B. Produktpässe wichtige Informationen über ein Produkt für Upgrades, Wartung, Reparatur und Wiederverwendung liefern. Mess-, Steuer- und Regelungstechnik helfen dabei, mit variierenden Mengen und Qualitäten zurückgegebener Produkte am Ende ihres Lebens umzugehen, wertvolle Stoffe zurückzugewinnen und Recyclingprozessen effizient zu betreiben. Der weitere Ausbau der digitalen Infrastruktur und die Digitalisierung im Allgemeinen können somit die Einführung der Kreislaufwirtschaft weiter unterstützen und ermöglichen.

**8**

**Neben etablierten IT-Werkzeugen sollten neue, vielversprechende Technologien wie Blockchain und Künstliche Intelligenz (KI) eingesetzt, erprobt und weiterentwickelt werden.**

Neue IT-Technologien wie insb. Blockchain und Künstliche Intelligenz bieten ein enormes Potenzial, um den spezifischen Anforderungen der Kreislaufwirtschaft gerecht zu werden. Sie können helfen, die komplexen Systeme einer Kreislaufwirtschaft zu verwalten, mit variierenden Mengen und Qualitäten von Materialien umzugehen, die Nachverfolgung von Materialien und Produkten durch ihre verschiedenen Lebenszyklen zu unterstützen, Informationsbedarfe zu befriedigen und die Planung und Steuerung von Kreislaufwirtschaftssystemen auf der Mikro-, Meso- und Makroebene zu unterstützen. Daher sollten diese Technologien und ihr Einsatz in der Kreislaufwirtschaft weiter erforscht, entwickelt, getestet und angewendet werden.

**5**

**To fulfill the energy demand in a Circular Economy, the long-term goal for Germany and the major part of the world should be to achieve a complete sustainable energy supply. This requires the development of efficient technologies as well as the use of transition technologies.**

Due to the second law of thermodynamics every conversion process is associated with the loss of usable energy. Thus, an external input of energy is necessary to enable the provision and flow of materials in a CE. To avoid adverse effects on the climate this energy needs to be supplied in a sustainable way. Therefore, Germany and the major part of the world should transform their energy system completely towards a sustainable supply and distribution of energy. This requires research and development on efficient technologies to finally achieve this goal. Until these are deployable on the global scale, transition technologies may be needed. These have to be discussed thoroughly regarding their necessity as well as adverse effects on other sustainability criteria, associated risks and costs.

**6**

**The sustainability goals regarding CE and energy are only attainable on a global scale. Potential conflicts between the local, regional, and global level have to be resolved. This holds for energy supply but also import and export of resources, used products and waste.**

Reaching the sustainability goals is a global task. The SDGs have been adopted as a global agenda for the year 2030. As we live already in a globalized world and products and services are manufactured and provided in multiple, interlinked, and global value chains and delivered to customers worldwide, CE and energy supply have to be thought on the global scale as well. At the same time, regional and local solutions to closing material loops or providing energy are often preferable and the export of End-of-Life products and waste to other parts of the world are problematic from an environmental and questionable from an ethical perspective. Thus, resource import, and export of resources, used products and waste as well as energy supply need to be dealt with taking into account the three levels. The development of sustainable circular solutions needs to resolve potentially conflicting objectives with regard to these aspects.

**7**

**We need a powerful digital infrastructure and a high grade of digitalization, which has to be further promoted, especially in the public sector and in small and mid-sized enterprises (SME) in Germany.**

Digitalization and the provision of a powerful digital infrastructure are important enablers and drivers for a CE. E. g., product passports can provide important information on a product for upgrades, maintenance, repair, and re-use. Sensing and control help to deal with varying amounts and qualities of returned products at the end of their life and facilitate recovery of valuable substances and efficient operation of recycling processes. The further development of the digital infrastructure and overall digitalization among all stakeholders thus may further support the deployment of the Circular Economy.

**8**

**Besides established IT-tools, new promising technologies such as blockchain and artificial intelligence (AI) should be applied, tested, and developed.**

Especially new IT technologies such as blockchain and Artificial Intelligence provide a huge potential to deal with the specific requirements of the CE. They may help to manage the complex systems of a CE, deal with varying amounts and qualities of materials, support tracing of materials and products through their different life cycles, mine information and support planning and control of CE systems on the micro, meso and macro level. Therefore, these technologies and their use in CE should be further investigated, developed, tested, and applied.

**9**

**Neue quantitative Methoden für eine ganzheitliche Nachhaltigkeitsbewertung von kreislaufwirtshaftlichen Lösungen sind notwendig, um negative Effekte durch einseitige Priorisierung zu vermeiden und die Anstrengungen auf wirklich nachhaltige Lösungen zu fokussieren.**

Kreislaufwirtschaft stellt oft breite und umfassende Lösungen bereit, die verschiedene Teile eines Systems und mehrere Nachhaltigkeitskriterien betreffen. Da Kreislaufwirtschaft nicht als Selbstzweck betrachtet werden darf, sondern mit den allgemeinen Nachhaltigkeitszielen in Einklang gebracht werden muss, reichen „einfache", d. h. eindimensionale Kennzahlen, die sich auf die Kreislaufführung allein konzentrieren, nicht aus. Vielmehr sind ganzheitliche, konsistente und mehrskalige Bewertungsmethoden erforderlich, um den Status quo, die potenziellen Vorteile und die Entwicklungspfade in Richtung Nachhaltigkeit durch kreislaufwirtschaftliche Lösungen wirklich bewerten zu können. Aus der Fülle von Metriken, Indikatoren und Bewertungsansätzen, die in der Kreislaufwirtschaft angewendet werden, bieten insbesondere Ökobilanzierungen und Nachhaltigkeitsbewertungen (Live Cycle Sustainability Assessments) sowie Stoffstromanalysen (Material Flow Analyses) gute Ansatzpunkte. Diese müssen jedoch weiterentwickelt werden, um die Nachhaltigkeitseffekte von kreislaufwirtschaftlichen Ansätzen und Lösungen zu erfassen. Insbesondere der Umgang mit Stoffkreisläufen, die Konsistenz über betrachtete Skalen sowie vorausschauende und konsequentielle Bewertung sind hier wichtige Arbeitsfelder.

**10**

**Wir brauchen maßgeschneiderte Kommunikationsinstrumente für Märkte und Kunden, um das gesellschaftliche Vertrauen und die Unterstützung für die Verbreitung von Lösungen für die Kreislaufwirtschaft zu erleichtern.**

Ein zentraler Punkt für einen erfolgreichen Übergang zur CE ist die Akzeptanz und Beteiligung der Stakeholder. Sie müssen in die Lage versetzt werden, gut informierte Entscheidungen über den Kauf und die Nutzung von Produkten und Dienstleistungen zu treffen. Außerdem müssen sie vertrauenswürdige und zuverlässige Informationen finden, die dies ermöglichen. Dazu ist es notwendig, maßgeschneiderte Kommunikationsinstrumente zu entwickeln, die diese Eigenschaften aufweisen.

**All diese 10 Botschaften und Empfehlungen müssen in Lehrpläne und Ausbildungsprogramme integriert werden, um Kreislaufwirtschaft in Theorie und Praxis zu implementieren und den Übergang zur Nachhaltigkeit im weiteren Sinne zu beschleunigen. Lehre und Ausbildung auf allen Ebenen (frühkindliche Bildung, Schule, Handwerk, Hochschule, lebenslanges Lernen) sind erforderlich.**

**Die Kreislaufwirtschaft erfordert einen grundlegenden Wandel hin zu nachhaltigen Systemen. Denken in Kreisläufen und Systemen und die interdisziplinäre Lösung komplexer Probleme bei gleichzeitiger Wahrung der disziplinären Exzellenz erfordern Kompetenzen, die in unserem derzeitigen Bildungssystem kaum vermittelt werden. Ihre Integration in Lehre und Ausbildung auf allen Ebenen ist daher eine Schlüsselaufgabe, wenn der Übergang zur Nachhaltigkeit gelingen soll.**

**9**

**New quantitative methods are needed for a holistic sustainability assessment of CE solutions to prevent negative effects caused by one-sided prioritization and focus efforts to truly sustainable solutions.**

CE provides often broad and comprehensive solutions affecting different parts of a system and multiple sustainability criteria. As CE must not be seen as a purpose in itself but should be aligned with the overall sustainability goals' "simple", i. e. one dimensional, metrics focusing on circularity alone do not suffice. On the contrary, holistic, consistent and multi-level assessment methods are needed to truly assess status quo, potential benefits and developments pathways towards sustainability through CE solutions. Within the plethora of metrics, indicators and assessment approaches applied in the CE, Life Cycle Sustainability Assessments and Material Flow Analyses provide good starting points. However, these need to be further elaborated to capture the sustainability effects of CE approaches and solutions especially regarding the circularity aspects, consistency through multi-level considerations as well as prospective and consequential assessments.

**10**

**We need tailored communication instruments for markets and customers to facilitate societal trust and support for the dissemination of CE solutions.**

A central point for a successful transition towards the CE is the acceptance by and participation of stakeholders. They need to be facilitated to take well informed decisions regarding purchases and usages of products and services. In addition, they need to find trustworthy and reliable information enabling this. Thus, it is necessary to develop tailored communication instruments providing these features.

**All these 10 messages and recommendations need to be integrated into curricula and training programs to deploy CE into theory and practice and accelerate the broader sustainability transition. Teaching and training at all levels (early childhood education, school, craft, college, lifelong learning) are required.**

**The CE demands for a fundamental shift towards sustainable systems. Circular thinking, systems thinking and interdisciplinary solving of complex problems while maintaining disciplinary excellence demand for competencies, which are – so far – hardly obtainable in our current education and training system. Their integration into teaching and training at all levels is therefore a key task when the transition towards sustainability shall succeed.**

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# Part II

## Recommendations for Action by the four Working Groups

# II.1. Sustainability requires Circular Economy

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# II.1.1. Recommendations for Action – Working Group I

**1**

**For the transformation to all-encompassing sustainability to be successful, the current acting in parallel of the stakeholders' politics, science, business, and civil society must be replaced by networked, interlocking acting.**

**2**

**In the process of transformation towards circular economy policymakers, researchers, industry, and society are obliged to simultaneously work on appropriate regulatory, economic and technological measures.**

**3**

**In the process of planning a future-oriented circular economy eco-effectiveness should definitely be granted greater importance than eco-efficiency.**

**4**

**Circular Economy in accord with economic and societal diversity are essential tools for achieving sustainability as long as "engineering" the environment does not run in conflict with the life enabling processes of nature.**

**5**

**Circularity without respecting the entire natural system is not enough: Only a holistic environmental impact assessment can prevent negative effects caused by one-sided prioritization.**

**6**

**Circular processes require to preserve the inherent quality of materials, components, or subsystems throughout the whole life cycle.**

**7**

**What we need is a pricing of the use of resources, which reflects ecological and social effects, especially under the aspect of protecting the commons.**

**8**

**Sustainability and Circular Economy need to be firmly integrated into the educational canon (early childhood education to academic training) across all disciplines to raise awareness and accelerate action.**

## Annotation

**The following texts of Part II.1. have been developed on the basis of contributions from and discussions with the participants of the Working Group "Sustainability requires Circular Economy".**

# Working Group I – Sustainability requires Circular Economy

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# II.1.2. Explanations

**1**

**For the transformation to all-encompassing sustainability to be successful, the current acting in parallel of the stakeholders' politics, science, business, and civil society must be replaced by networked, interlocking acting.**

The basis of life and survival of the human species is our earth system, which provides the resources necessary for life and absorbs and processes the emissions generated by production and consumption. At the latest with industrialization, the exponential growth of the world population, and rising living standards, we are reaching the limits of our planet's carrying capacity in terms of both resource consumption and emissions (Planetary Boundaries). Parallel to this development, more and more anonymous global structures have emerged that have pushed people into the background. Important decisions are not made according to the basic needs of people and the environment, but according to economic interests – in short: money is valued more highly than people.

Developments in recent years have been dominated by specific measures. These have undoubtedly led to significant progress in environmental protection, for example, but they were also often associated with tradeoffs that were not taken into account. Moreover, the four stakeholders have mostly acted independently of each other – in self-interest and/or in the common good.

Against this background, a paradigm shift is inevitable on the way to sustainability: holistic instead of particularistic strategies and decision-making structures!

In addition to the holistic environmental accounting rightly called for by Grambow, holistic sustainability accounting that implies social and economic impacts will also be required in the future.

Equally decisive for success is that in the future the four stakeholders of sustainability do not act side by side, but with each other – with the primacy of the common good under consideration of individual interests.

With this new approach, we must put all previous processes of production and consumption to the ecological and social test and "reinvent" ourselves wherever necessary.

Goals must be defined, and guard rails established that preserve our livelihoods, secure economic stability, and enable a dignified life for all following the precept of sustainability: no one lives at the expense of another – neither at the same time nor with a time lag.

Under these premises, the circular economy must also be redefined as an essential solution for the sustainable use of resources – a sustainable circular economy is more than a circular economy!

**2**

**In the process of transformation towards circular economy policymakers, researchers, industry, and society are obliged to simultaneously work on appropriate regulatory, economic and technological measures.**

The transformation to a circular economy is not only one of the most challenging tasks for our society in terms of content. It is also one of the most comprehensive multi-stakeholder processes when it comes to the number of stakeholders involved and to be involved. Even if the target picture is indisputable and there is also unanimity on the tasks of each, stakeholder groups too often wait for each other to move first. If the "movement" also contains an economic element in the form of additional investments, higher costs or the reallocation of budgets, every "first mover" feels additionally economically at risk. In addition, any change process carries the risk of shifting market positions between competitors to the disadvantage of whoever makes the first move. Two examples will illustrate this.

The first example describes the joint effort of the European detergent industry to offer their powder products and liquid detergents in an increasingly compact form. In order to rule out prohibited agreements, no uniform compacting specifications or fixed changeover dates are agreed, but rather time intervals of 12 months, in which competitors are free to choose the date between announcement and changeover. A concentration interval is also planned for the compaction itself, in which each competitor can move freely. Experience over several decades shows: Those who first switch to smaller formats with the same number of wash loads lose market share when the price is the same. The reason for this is consumers' preference for packages with a larger volume, even if prices and the number of wash loads contained are identical. As a result, all competitors do not actually switch until the end of the time interval. And what's more, companies generally only switch to the minimum concentration, even if it is technically possible for them to achieve the maximum concentration. The environment, consumers and also the economy alike only suffer disadvantages. A remedy can be found in which, under the strict supervision of the EU Directorate General for Competition, a permitted agreement open to all market participants is carried out, so that all market participants, coordinated at the same time, make the identical product change in order to neutralize the above-mentioned consumer preference.

The second example describes a thought experiment of acatech's Circular Economy Initiative Germany. As part of a thought experiment, the regulatory, technological and economic parameters were modeled that would enable a closed loop for 3 million tons of plastic packaging annually as early as 2030. To achieve this, a capacity of about 700 thousand tons/year for chemical recycling must be created in Germany for packaging plastics alone. Plastics manufacturers and recycling companies will only make this investment if they can expect a corresponding purchase. Consumer goods manufacturers would be happy to signal the need if chemical recyclate were also credited to them as recycled plastic in the same way as is currently the case only for mechanically recycled plastic. This, in turn, already requires an amendment to the Closed Substance Cycle Waste Management Act and the Packaging Act. However, this is currently refused by the legislator with the argument that there is not enough capacity in the market to initiate a change in the law now.

Analogous examples can easily be found in the other areas of the circular economy. What they all have in common is that the chicken-and-egg problem can only be solved if, in addition to all the factual agreements, another prerequisite is created: mutual trust.

**Conclusion: The success and speed of the transformation to a circular economy are very much dependent on a non-material prerequisite: mutual trust.**

**3**

**In the process of planning a future-oriented circular economy eco-effectiveness should definitely be granted greater importance than eco-efficiency.**

### From eco-efficiency to eco-effectiveness: consequences for the circular economy

Eco-efficiency and eco-effectiveness are significant approaches for implementing sustainable development. In general, they aim to preserve the carrying capacity of the Earth and reduce the consumption of finite natural resources. However, the degree of impact between eco-efficiency and eco-effectiveness differ quite substantially. The focus has long been on eco-efficiency, which aims to optimise industrial processes by combining the reduction of resource use and pollution while increasing economic efficiency based on the technological state of the art.

Eco-effectiveness on the other hand – sometimes the terms eco-consistency or eco-compatibility are used as alternatives – is a broader concept. It strives for a structural change in favour of the compatibility of nature, decent work, and technology, including its implementation. Among other things, the concept aims to avoid waste by, processing reusable resources through recycling, among other things. The social dimension plays an important role in the context of eco-effectiveness. The optimisation of the social system should contribute to the harmonisation of the human-made technical system and the natural ecological system. Thus, while eco-efficiency focuses on the optimisation of individual products or production processes in terms of ecological sustainability, eco-effectiveness is concerned with the sustainable orientation of overall economic production and consumption.

The necessary sustainable structural change is sought through innovations in which material flows are harmonised with nature. The compatibility of the technological system with nature, as sought by eco-effectiveness, is based on an ideal-typical system of closed material cycles. This leads to considering the idea of a circular economy in a larger context. Accordingly, economic processes are oriented towards the material cycles of nature, as Kenneth Boulding, one of the first environmental economists, stated as early as 1966. The goal of the circular economy is to manufacture products in such a way that they can be reused, repaired, recycled, and their components used as the basis for new products with little financial and energy expenditure. Consequently, waste becomes redefined from a "crushing burden" on nature and people to an input factor for manufacturing new products. This maintains the stock of natural resources and minimises the emission of substances that are harmful to nature and the health of people (consider replacing with public health).

Two popular examples in this context are cradle to cradle and blue economy. The cradle-to-cradle principle is based on the assumption that "everything is a nutrient", following the example of nature. Materials from discarded consumer goods are returned to their producers to be reused for new products. This so-called "eco-leasing" allows consumers to use products, while producers benefit from retaining ownership of high quality, recyclable materials.

Another successful concept of eco-effectiveness, especially in the Asian region, is the blue economy. Here, in addition to recycling products and resources, synergy effects are of great importance. One central element of a blue economy is the cooperation of different partners. Therefore, industrial alliances are established wherein materials circulate as input and output.

Eco-effectiveness gained great significance through the idea of a circular economy and is of outstanding importance for sustainable development through its practical application examples. So far, however, the structural change towards a broad-based circular economy is still quite slow. In other words, there is still great, untapped potential for a consistent circular economy.

**4**

**Circular Economy in accord with economic and societal diversity are essential tools for achieving sustainability as long as "engineering" the environment does not run in conflict with the life enabling processes of nature.**

It is scientifically undisputed that life has existed on our planet Earth for over 4 billion years. During this long period of time, the Earth has been exposed to numerous disastrous events (e.g., impact of asteroids and volcanic eruptions) and massive climate changes. Some species were unable to survive the consequences of such threats. Nevertheless, life as such has asserted itself. How could this happen?

Characteristic for planetary life is its inherent capacity of self-preservation (V. Gorshkov, 2000: "biotic regulation"). Equally important are the basic principles of ecology such as biodiversity, redundancy, and in this context also various natural circular processes, the water, the oxygen and the carbon cycle for instance. In the era of Anthropocene (P. Cutzen, 2016) gaining a deep respect for these basics of life is the most urgent obligation of mankind. In this respect a large fraction of today's mankind proves to be advice-resistant, unfortunately.

Redundancy in ecological systems allows species and bio-communities which cannot cope with changes of the environmental (e.g., climate) are replaced by those that can adapt. The problem is that humankind embraces mono-cultural systems for the sake of swift profit making. There is traditionally too less redundancy embedded in the current societal, political and economic systems, worldwide, unless nature through epigenetic processes would come up with an upgraded version of Homo Sapience, Homo Sapience 2.0.

Concerning natural circular processes, the most important principles of the oxygen and the carbon cycle are part of the basic biological education in schools and universities, and does not need to be further explained here, therefore. In contrast, the water cycle related to forest ecosystems needs specific attention, however. (Figure 1)

**Important steps of the forest** related water cycle include:

- Evapotranspiration in forests, meadows, wetlands, as well as by creatures of all kinds (i.e., transition of liquid to gaseous water). Thermodynamically, evaporation is associated with a drop of temperature, which in biological systems is used to control the body temperature of plants, animals and humans.
- Condensation (i.e., transformation of gaseous to liquid water) is associated with a rise of temperature in a gaseous atmosphere causing a hermal lift which in turn enables the transport of water against gravity in vertical direction, called "biotic pump" (A. Makarieva, 2010; F. Pearce, 2020). In addition, decrease of the water vapor partial pressure causes a flow of water gas from higher to lower gaseous partial pressure zones, mainly in horizontal direction which owns the potential of transporting water towards the inland (called a "flying river") provided uninterrupted forest area over large distances.
- Aggregation (i.e., transformation of small aerosols of liquid water to large size droplets, graupel, hail or snow) appears when condensates escape into the atmosphere above the forest canopy.
- Precipitation (i.e., fall-down of aggregated liquid water) with the chance to feed ground-based vegetation with water, but also to fill ponds, rivers and groundwater bodies.
- Uptake of the precipitated water by plants and animals, particularly those living in forest ecosystems.
- Maintenance of this sequence of processes is crucial for sustaining forest ecosystem function. Any interruption of the sequence of processes listed above inevitably leads to drought situations, water scarcity and economic losses, as currently demonstrated worldwide – including in Bavaria.

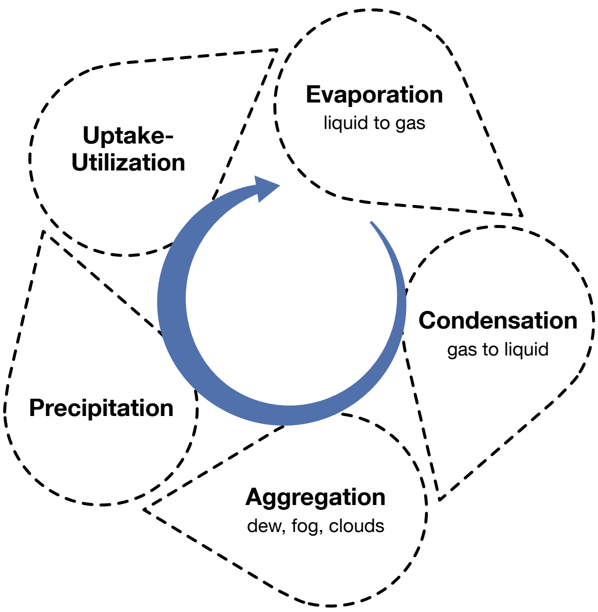


Figure 1: Atmospheric Water Cycle
Source: Author

The idea of replacing natural cycles with technical measures (geoengineering) bears traits of hubris (ancient Greek mythology), when underestimating the complex, intertwined nature of ecosystems. Among the technical measures currently under dispute are technologies such as cloud seeding and emission of electrically charged ions (Wilderer et al., 2011). In case of positive effects such methods might help quickly reducing threats associated with drought conditions, but only in vertical direction and in the vicinity of the seeding/emission sites. The better, while sustainable solution is to preserve or re-establish large scale forest ecosystems, even so this needs time and patience.

**5**

**Circularity without respecting the entire natural system is not enough: Only a holistic environmental impact assessment can prevent negative effects caused by one-sided prioritization.**

Circular economy can only be considered a pillar of sustainability if the integrity of all relevant subsystems involved (water, soil, biodiversity, air) are treated explicitly as equivalent goals. This includes the issue of natural resources. Circular economy is not an inherent end in itself but creates a way of doing business consistent with the goals of sustainability.

The typical mistake of the Anthropocene is that an action achieves certain ends but also has side effects which cause damage in other relevant sectors (externalization) or even counteract the purpose itself (Grambow et al.).

For instance, renewable energy technologies reduce $CO_2$ emissions. This makes them a means of combating climate change. But they also have detrimental effects. Wind turbines, for example, cause bird strikes, free flowing rivers are impounded for hydroelectric power plants whose turbines are harmful to fish, photovoltaics "consume" land. The generation of renewable resources requires land. They "consume" land and water by causing erosion and pollution from pesticides and fertilisers. We know from Paul Crutzen, author of the concept of the Anthropocene, that not only climate change creates crisis conditions, but also the scarcity of clean water and healthy soil. We have to be concerned by the degradation of ecosystems as well as the loss of biodiversity and the degradation of good living conditions causing social tensions and societal destabilization (Welzer).

It obviously makes little sense to fight one crisis while causing (perhaps greater) damage to another equally important area of interest. Nevertheless, the failure to recognise such conflicting goals is the rule rather than the exception, regularly driven by interest groups whose economic success depends precisely on a certain, often path-dependent technology and who are actively seeking to prevent the establishment of the necessary balance between the conflicting goals by setting narcissistic priorities (IAS, 2008).

Only holistic goal descriptions can help to prioritize the well-recognized sustainability goals while taking interdependencies between the relevant sectors into account. These goal descriptions do not allow monochromatic objectives such as "climate change is the political priority number one, thus any form of renewable energy is more important than the preservation of the water balance, soil, ecology and social justice".

The most promising procedure for implementing the necessary balancing processes is an "environmental impact assessment", which must include all the relevant subsystems. The scientific challenge is to appreciate the importance of undisturbed subsystems such as water-, soil-, air- and eco-systems, and to understand the threats caused by any kind of violation and disintegration. The political challenge is to enforce the protection of these subsystems even when their reaction to pressures is delayed, sometimes for several generations. It is important to act against those stakeholders who place their particular interests over respecting the natural constraints of the system and its subsystems.

**6**

**Circular processes require to preserve the inherent quality of materials, components, or subsystems throughout the whole life cycle.**

**Recommendations for action**

- At the end of the service life of a product, reusability (recycling) or higher-quality usability (upcycling) must be ensured; lower-quality use (downcycling) must be avoided at all costs.
- Therefore, it is necessary to ensure long-term usability with regard to both the choice of materials and construction.
- Information on the chemical and physical properties of the materials, components or subsystems used must be recorded and kept available throughout the entire life cycle.
- The structural connections must be designed in such a way that components and building systems can be disassembled non-destructively to ensure loss-free reuse.

**The role of the construction industry**

The construction industry is one of the most resource-intensive sectors of the economy and generates more than half of the total waste produced in Germany. This means that the construction industry has enormous potential for savings, which gives it a key role in implementing the politically demanded and ecologically necessary resource efficiency. In order to fundamentally reduce material consumption, the current practice of linear material use (cradle to grave) must be replaced by a consistent implementation of closed cycles (cradle to cradle). Here, existing materials and products are reused, refurbished and recycled for as long as possible.

**Buildings as material banks**

The anthropogenic material stock in Germany offers an enormous raw material potential, which, in addition to infrastructures, such as road, rail and water networks, can be found primarily in buildings. Combined with future development scenarios on lifetimes, the quantities of material embedded in our built environment can contribute – when reused – significantly to improving resource efficiency and reducing $CO_2$ emissions in the construction sector.

In order to counteract rising costs and the challenges of supply and disposal security and to develop the building stock more sustainably, the use of secondary raw materials and the establishment of material cycles must be accelerated. In particular, the materials currently bound in the building stock represent great potential for substituting and saving primary materials. In addition, by reusing building materials as extensively as possible, waste volumes can be drastically reduced and landfill bottlenecks alleviated.

**The way future buildings have to be built**

In the area of new construction, the principle of the circular economy in the sense of "recycling-friendly planning" must be firmly anchored in the thinking of planning architects and engineers (Figure 2). Similarly, the goal of future-oriented planning of buildings must be to avoid or delay later deconstruction and subsequent reuse as far as possible, since deconstruction is always fundamentally associated with resource consumption. On the one hand, a long useful life of buildings can be supported by the use of durable materials – on the other hand, buildings should be designed so flexibly that they can be easily adapted to changing requirements.

**Milestones on the way to a circular construction industry**

A successful transition to a circular economy requires reliable and standardized information on material flows and the composition of building products and buildings. An important tool that can provide the necessary methodology and data structure for collecting and processing the relevant information is the so-called material passport.

In addition to providing relevant material data, digital material passports also support planners and other decision-makers in the planning and implementation of recyclable building components, systems and buildings, among other things. For example, digitally available data sets can also store information on fasteners and on the assembly or disassembly of components and systems. By keeping the information contained in the BIM model or material passport up to date over the entire life cycle of the building, sustainable life cycle management for materials, products and buildings is made possible.

Standardized digital information exchange enables the fundamental transition to a comprehensive circular economy in the construction industry.

**7**

**What we need is a pricing of the use of resources, which reflects ecological and social effects, especially under the aspect of protecting the commons.**

**Recommendations for action**

- In their annual reports on economic growth, the economic authorities may be guided by more state-of-the-art, more comprehensive indicators, as they have been discussed and presented by the scientific community for years.
- Political decisions, especially laws, should be assessed against such indicators as the sustainable development goals index and these assessments should be publicly communicated with every decision (cf. the decision of the BVerfG on the Climate Protection Act of 29.04.21), in order to allow political opinion-forming on the sustainability of measures taken and their effects in the sense of the UN's Sustainable Development Goals (SDG).

Turn the look.

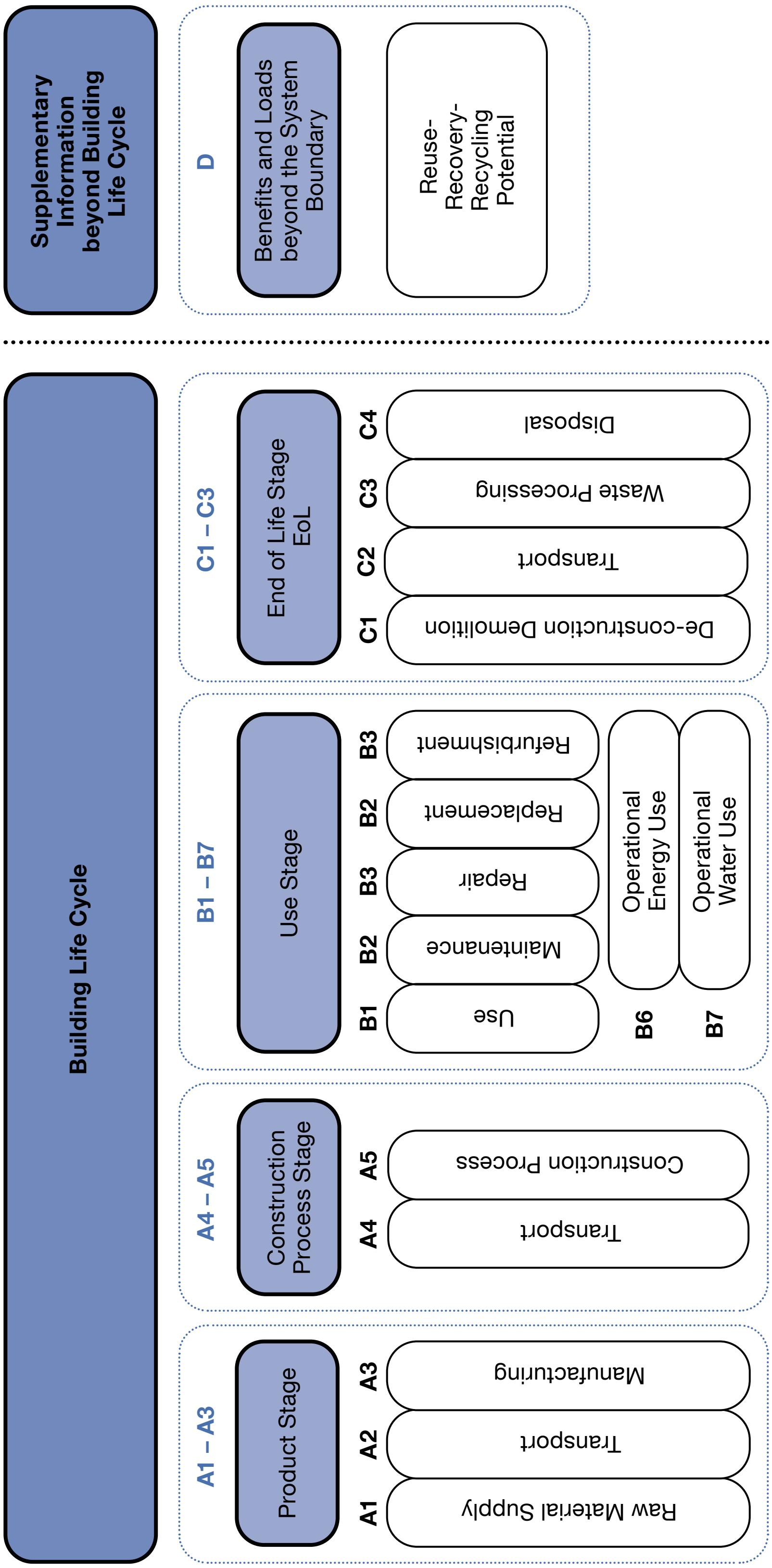


Figure 2: Life Cycle of a Building
Source: Autor

**Applying a broader concept for measuring economic growth**

Current start-ups and other venues aimed at a sustainable business model like urban farming companies often face difficulties explaining their story to a market which is focused on profitability, often on a short time scale. The social benefits and advantage of these enterprises cannot be measured by adequate KPIs which become effective for investment decisions, due diligence processes – or even appliance of regulatory conditions. Hence socially beneficial companies looking for investors have to compete with other "hype" investments, despite them being less contributive to the common good.

Main reason for this difficulty is that the current underlying financial indicators of economic growth, at the top level the gross domestic product (GDP), do not reflect all aspects of the real resource consumption of economic activity. To lay a path towards a sustainable economy, all factors that prove to be unsustainable must be reflected in an expanded definition of this indicators. As a measure for the definition of a more general indicator for economic growth, the condition of all resources, in particular of those previously considered common goods, such as air, water, land, biodiversity, etc., before use or pollution may be used, so that the costs that would be necessary to restore the resources to their previous condition (e. g. through cleaning) can be measured and taken into account.

Here, the economic sciences are called upon to further develop the approaches of the Index of Sustainable Economic Welfare (ISEW) or its successor Genuine Progress Indicator (GPI), but above all to communicate them more broadly, as already called for in 2007 in the conference "Beyond GDP" by the EU Commission, European Parliament, Club of Rome, OECD and WWF, and presented as a roadmap in https://ec.europa.eu/environment/beyond_gdp/index_en.html. Publications such as the 2019 Europe Sustainable Development Report should be strengthened in the public perception and understood as a basis for political action alongside the traditional key figures, if not replacing them.

Such an extended view of the entire economic modelling should also be reflected in the real product prices, e. g. by allocating the recorded burden variables in the form of taxes such as the $CO_2$ tax to corresponding production processes, in order to arrive at a more realistic view of "resource consumption" on a unit cost basis on the one hand, which includes the burdens on the comparison of a "non-production", but on the other hand also to make the real costs of the burdens on common goods transparent to the consumer.

Looking at the scientific discussion on this topic, there has not been a lack of approaches and proposals since the 1990s, but rather a lack of public and political awareness and an enforcement of the use of such expanded indicators.

**8**

**Sustainability and Circular Economy need to be firmly integrated into the educational canon (early childhood education to academic training) across all disciplines to raise awareness and accelerate action.**

The change toward the circular economy seems inextricably linked to a transformation toward sustainability. For a successful change, all stakeholders – direct and indirect – need to be addressed. The stakeholders of the circular economy (Figure 3) are recruited from many different disciplines, such as engineering, environmental science, economics, law, sociology and many more. The majority of thought leaders, facilitators, pathfinders, designers and implementers, who shape sustainable circular economy with much interdisciplinary expertise, systemic thinking and perhaps also intrinsic conviction emerge out of these areas. Above all, they are needed to further develop and permanently establish a sustainable circular economy, and they should serve as role models/multipliers, also with regard to the required readiness for change among all stakeholders.

To achieve this, all stakeholders need education and awareness on both circular economy and sustainability. However, today, neither sustainability nor circular economy are included in the education of most of these actors. Therefore, there is an urgent need to integrate sustainability and circular economy into the curricula of these disciplines and in order to further accelerate and comprehensively drive change, integration into the curricula of all disciplines is beneficial.

Furthermore, every citizen is a stakeholder of sustainability and circular economy at least as a consumer. Therefore, these topics need to be taken further into society and a living culture of responsibility needs to be anchored in society. To this end, sustainability and the circular economy must be integrated into the entire educaltional canon illustrated in figure 4 and not only into school or academic education.

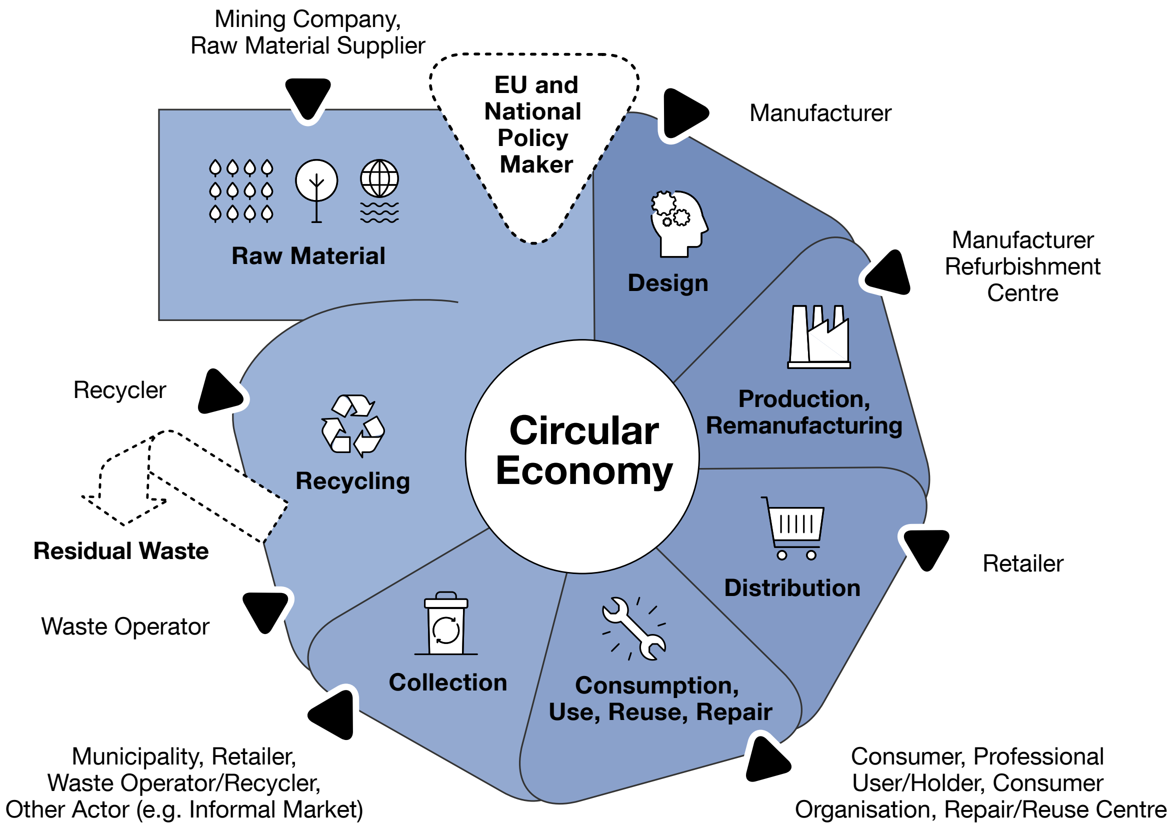


Figure 3: The stakeholders of Circular Economy
(according [1] European Recycling Platform)

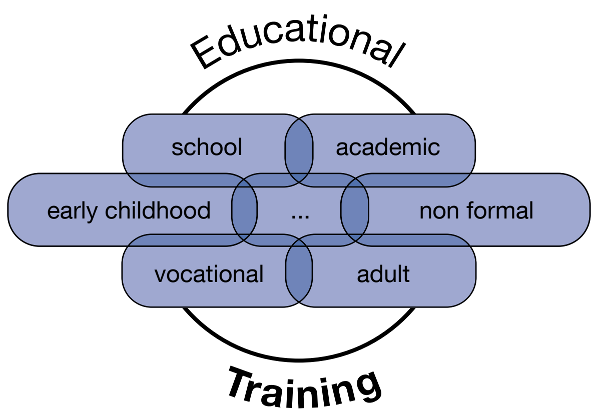


Figure 4: Types of education and training in which sustainability
and Circular Economy need to be integrated

# II.1.3. References

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# II.2. Circular Economy and Sustainable Energy

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# II.2.1. Recommendations for Action – Working Group II

**1**

**Goals and actions must be derived from societal objectives. Technology/engineering must serve social change.**

- Environmental neutrality
- Sustainability (social, ecological, economic aspects)
- Conservation of resources

**2**

**New materials/technologies/processes for achieving societal objectives should be developed while taking account of their environmental footprint (renewable, recyclable).**

- E. g., nano-membrane technology for water purification, catalysts for enhancing chemical reactions
- E. g., Life Cycle Assessment of PEM (poly electrolyte membrane) electrolyser by means of photovoltaics, changes in the production of materials

**3**

**Teaching, training and further education to raise awareness of the objectives in point (1) and their implementation on all levels of education (kindergarden, school, continuing professional development, apprenticeship, academic education)**

- E. g., life cycle design as part of engineering
- Well-trained craftspeople as a basis for implementing new sustainable technologies, new teaching contents, more flexibility and transparency of technical colleges (FH) and technical universities (TU) towards handicraft, continuing professional development, live-long learning

**4**

**Call for openness towards new technologies/ideas, demonstrate its significance, motivate trust in research and development by successful examples mirroring objectives of point (1).**

- Science and engineering must take responsibility for reaching the objectives mentioned in (1)
- Innovative and new technologies must be examined for their societal impact

**5**

**The regulatory framework must be shaped in such a way that those technologies prevail which have a positive impact on the objectives in (1) while remaining cost-efficient.**

- Sustainable pricing: External costs to be agreed on an international level/EU-ETS
- Green Dot ("Grüner Punkt") symbol and efficiency-labeling as a source of information
- Bottle deposit scheme
- Aim for internationally recognized/harmonized certification

**6**

**Internationalizing energy supply in competition with local self-sufficiency must also always be aligned with the criteria in point (1).**

- Taking account of geographic and social conditions (availability of land, wind, solar radiation)

**7**

**Strengthening a circular economy of energy and materials.**

- E. g., use of waste heat and circular flow of heat
- E. g., decreased demand for energy in raw materials industry by more recycling/light-weight construction/longer life cycles

**8**

**Transition technologies are necessary as a step toward the objectives and in offering an opportunity to advance carbon-neutral technologies. Possible technological lock-ins need to be considered.**

- E. g., colors of hydrogen

## Annotation

**The following texts of Part II.2. have been developed on the basis of contributions from and discussions with the participants of the working group "Circular Economy and Sustainable Energy". Not all recommendations reflect the opinion of all participants.**

# Working Group II – Circular Economy and Sustainable Energy

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# II.2.2. Explanations

1

**Goals and actions must be derived from societal objectives. Technology/engineering must serve social change.**

- Environmental neutrality
- Sustainability (social, ecological, economic aspects)
- Conservation of resources

Every technology has an impact on the environment, climate, resources, and society. This always results in conflicts between different objectives for optimization: Cost/profitability, $CO_2$ abatement costs, environmental and climate impact, conservation of resources, sustainability, acceptance/participation.

It is the job of science and engineering, e.g., by using scenarios, to demonstrate the options and consequences of different actions and their interactions with objectives. Policy makers must evaluate these scenarios and weight their different aspects to take appropriate decisions and/or adapt previous decisions to current findings. The circular economy has a particular part to play here. If structured in a sensible way, it offers an opportunity for conserving resources and protecting the environment while at the same time creating new opportunities for adding value.

Environmental neutrality comprises several individual aspects and/or systems, for each of which planetary or regional/local boundaries (tipping points) can be defined, which must be adhered to in a sustainable circular economy. Besides the important aspect of climate change, social conflicts and other kinds of environmental impact should also be perceived more clearly and taken into account, e.g., conflicts between poverty reduction and cost for climate change have to be balanced. As $CO_2$ certificates or levies put a price on the harm caused by $CO_2$ emissions, other forms of environmental damage or pollution must also be priced in such a way that they remain below the tipping points – see e.g., ExternE study of the European Commission: https://ec.europa.eu/transport/themes/sustainable/internalisation-transport-external-costs_en.

It is therefore worth considering how other environmental impacts can be given a monetary cost and how they can be appropriately accounted for. As shown in Figure 1, on the one hand, the limits for individual aspects are not yet all known, while on the other hand, there are five aspects exceeding the boundaries, three of them very clearly.

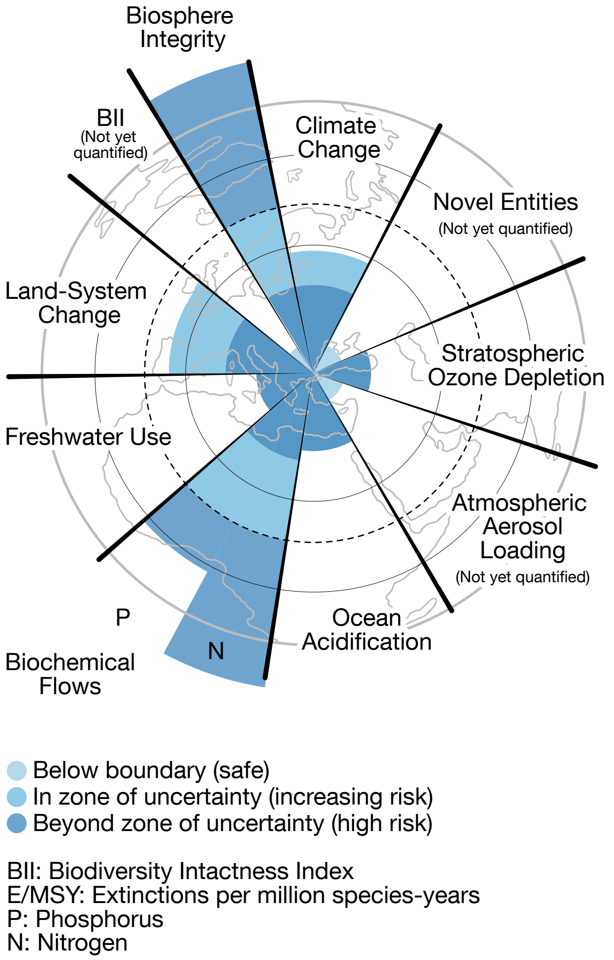


Figure 1: Planetary boundaries

Source: J. Lokrantz/Azote based on Steffen et al. 2015

Taking adequate account of the external costs of resource use requires not only pricing per se, but also a socially equitable distribution across all social classes. A sustainable way of life must not become a status symbol but must be the baseline standard globally. This means designing the necessary technological options accordingly and making them available to people.

Regarding energy supply, this will require efficient and considered energy use even in case of an energy transition to only renewable energy.

**2**

**New materials/technologies/processes for achieving societal objectives should be developed while taking account of their environmental footprint (renewable, recyclable).**

- E. g., nano-membrane technology for water purification, catalysts for enhancing chemical reactions
- E. g., Life Cycle Assessment of PEM (poly electrolyte membrane) electrolyser by means of photovoltaics, changes in the production of materials

The transformation of the energy system from fossil fuels to renewable energies entails a notable shift of environmental impacts from the operating phase to the production phase of renewable generating plants and/or problems with the disposal of old installations. Thus, a review of the entire life cycle becomes a necessary condition for implementing new environmental standards, particularly for reducing greenhouse gas emissions. For research, this means a new focus on the area of materials development and process engineering, as a basis for the production of materials.

The production of a handful but for now-a-days economy decisive materials has a huge impact on the worldwide energy consumption. Although a certain saturation in the needs for those materials might occur, a considerable reduction in its usage is not to be expected. New technologies and processes are often based on existing and known materials. Starting from established material behavior, processes are optimized, and innovation is generated. It is only with new – previously unknown – materials that really big steps or "eruptive" transformations can be achieved, as these new materials have new material properties.

One example of how a rapid improvement of energy efficiency in production processes can be achieved with new materials is organic solvent nanofiltration (OSN). OSN is a membrane separation method for separating a dissolved substance with a molar mass in the range of 200 – 1000 g/mol from an organic solvent. It has the potential to replace many thermal separation methods (e. g., concentration, distillation, rectification). As a rule, no thermal energy is required, as the separation is achieved by a difference in pressure across membranes, so that the solvent does not need to be evaporated. These gentle processing conditions, at room temperature, can result in higher quality especially of heat-sensitive products (e. g., in the food and pharma sectors).

Compared to distillation, savings of thermal energy of more than 90 % are possible with OSN; however, to create the pressure differential, additional power amounting to around 5 to 10 % of the thermal energy saved is required [1]. It has a large range of potential applications, starting in pharmaceuticals, fine chemicals, and food production areas and, with experience and after a commensurate decrease in cost, expanding to the basic chemicals sector, leading to total thermal energy savings of more than 100 PJ per annum.

Such leaps in energy efficiency through new materials and new processes are often disregarded in current considerations for a carbon-neutral energy supply to manufacturing and industry. Other new materials in the area of adsorption and absorption or improved catalysts will also contribute to a reduced specific energy demand in manufacturing and industry.

Let us illustrate this with the example of photovoltaics. The silicon solar cell has been mainstreaming for decades and has been optimized with respect to its efficiency. Thus, it has been successful and become widespread in commercial applications. As a result of the material properties of silicon (high density, mechanical and optical behavior), silicon solar cells are heavy, brittle, inflexible and opaque. This limits their application to the currently well-known installation sites such as roofs and photovoltaics farms. The solar cells have a fixed connection to the electricity grid and are immobile. There is severely limited variability as to their design, and accordingly they are difficult to integrate into other areas. Originally, they were not intended for recycling, and solar modules are not optimized in that regard.

New materials such as organic donor and acceptor molecules make possible the manufacture of so-called organic solar cells. These allow for completely different areas of application. Organic solar cells are flexible and lightweight (as a result of the low density of the organic materials and because much thinner layers are used). They need not necessarily be connected to a fixed electricity grid, allowing for small portable solutions. With the thickness of the layer reduced by a factor of 100, there is also a considerable saving in the use of materials in manufacturing an organic solar cell compared to a silicon solar cell. Given the variety of molecules that can be used, there are opportunities for changing the color or transparency. Organic solar cells can thus open up areas of application impossible for silicon solar cells (façades, windows, clothing, ...). And so photovoltaics will become an option in areas currently still completely inaccessible to solar cells. Organic solar cell technology, as a recent development of the past few years, is still in an intensive development phase, so that the latest considerations regarding their future reuse can be taken into account in the choice of molecules. Recycling can thus be part of the planning from the start.

Another important aspect to consider is the energy input required for manufacturing the solar cells. Silicon solar cells require very high temperatures in materials production, while organic solar cells can essentially often be manufactured at room temperature. Using new materials here is key to drastically reducing primary energy input.

Furthermore, the new materials also necessitate using new production processes. Thanks to solvent-based manufacturing, organic solar cells can be produced by means of spray coating or printing. For silicon solar cells, on the other hand, high vacuum technology must be used. These are not only completely different requirements as to the complexity of technologies and processes, but also new opportunities for using new technologies and processes in manufacturing solar cells.

Ultimately, these new processes also allow completely new approaches for components of the future, such as combining solar cells with thin film batteries in a thin film component. The obvious problem of the lack of sunlight at night can be overcome by such an integrated component. Here again, it is important to understand that an integrated component is not merely a serial connection of a solar cell and a battery, which is already feasible today with silicon technology. A similar example is combining an organic solar cell with a triboelectric generator into a component making use of both solar and mechanical energy.

The hypothetical generation of hydrogen as a future secondary source of energy is another example showing the need to consider the entire production process of new technologies. Hydrogen is to be generated in two steps: (1) First, solar radiation is to be converted into electricity in a PV installation, and (2) the electricity is to be converted into hydrogen by means of electrolysis. In operation, this constellation would not lead to any greenhouse gas emissions. In fact, however, the production of silicon-based solar cells using existing technologies causes significant carbon dioxide emissions. Silicon is found in nature as oxidized $SiO_2$. By reduction with carbon, elementary silicon can be produced from this. As a second step, the elementary silicon must be purified to obtain so-called “solar grade” silicon. In a further step, this is then transformed into crystalline silicon. These blocks then have to be cut and treated further to manufacture the actual cell. All these processes require an enormous energy input. Overall, according to (UBA [Federal Environment Agency], 2019), this results in emissions in the region of around 0.07 kg of $CO_2$/kWh. This assumes a typically German solar yield of the module. If hydrogen is now generated by electrolysis, we then get a value of around 0.14 kg of $CO_2$/kWh for the hydrogen, assuming conversion and transport losses. This is very close to the value of 0.2 kg for natural gas.

In future, many improvements and increases in efficiency may be achieved in all production processes, and/or old solar cells can be recycled to a certain extent – although, to date, this has not really been optimized. Here, the hope is that a circular economy can be created, in which only small amounts of new silicon need to be added, and other materials required for PV modules are recycled as well. This circular economy would have the advantage of conserving resources, reducing emissions, and probably of a further significant reduction in cost becoming possible.

3

**Teaching, training and further education to raise awareness of the objectives in point (1) and their implementation on all levels of education (kindergarden, school, continuing professional development, apprenticeship, academic education)**

- E. g., life cycle design as part of engineering
- Well-trained craftspeople as a basis for implementing new sustainable technologies, new teaching contents, more flexibility and transparency of technical colleges (FH) and technical universities (TU) towards handicraft, continuing professional development, live-long learning

**Life cycle analysis in education and training**

Life cycle analysis is an established method, for instant described in ISO standard 14001. A variety of software tools and databases is available nowadays to support preparing life cycle analyses. But the correct application of a life cycle analysis cannot be replaced solely by using these tools – it requires appropriate education, training and continuous consideration of new developments.

Besides a life cycle analysis as a key method in circular economy research, work on a circular economy requires a portfolio of methodologies (e. g., carbon footprint, dynamic material cycle analysis; reserve/resource analysis) as well as knowledge of procedures in the circular economy (collection, sorting, shredding, dismantling, reuse, downscaling over several life cycles, reprocessing/repair, disassembly, melting down, purification, etc.) and their position in the technology cycle.

**Higher education**

Life cycle analysis is already present today in some university disciplines (usually as a marginal topic). Life cycle design, on the other hand, is rarely taught other than in specialist courses of study. This topic will play an increasingly important part in many disciplines, not just in engineering, where it is of obvious relevance. An understanding of so-called “Life Cycle Thinking” and of the circular economy is also of importance in economics, business studies, sociology, political science, or the teaching professions, among others. This training can be given along specific topics such as mobility or nutrition, or it can be designed methodologically. Further, environmental impacts are increasingly shifting from the operating phase of e. g., energy conversion plants or automobiles to the production phase. In engineering, however, the focus is still on optimizing and improving the operating phase. Therefore, in future, training in the area of life cycle analysis should become an integral part of any engineering degree. It is worth considering whether more mandatory practical work experience should be required at the beginning of an engineering course. This will help engineering students with their communication skills and an understanding of everyday practice in companies. Here, TUM and the School of Engineering and Design in particular should provide the relevant teaching. This should be supported by relevant research.

#### Apprenticeships and continuing professional development in trade and industry

What is required are skilled manufacturing workers/craftspeople able to consider circular economy with the necessary technical knowledge of innovative processes. In the coming years and decades, OECD countries will have an increasing shortage of specialist workers in the circular economy, due to the overvaluing of academic study while neglecting the training of skilled workers and craftspeople – be it in installation and commissioning or maintenance and service. New technologies can only really be rolled out across the economy if the relevant craftspeople with relevant training are available. Here, a debate on the principles of the structure of education and training in Germany would doubtlessly be useful. It should again be discussed whether universities for applied sciences and apprenticeships in trades can be better interconnected. That is to say, whether very demanding trade apprenticeships should not in future lead to a bachelor's degree. This does not mean that the apprenticeship should become more theoretical – apprenticeship in a trade must remain very practical.

For many years, the Learning Energy Efficiency Networks (LEEN) and BEENi (Bavarian Energy Efficiency Networks), in a collaboration between businesses and academia (supported by public funding) have been assisting small, medium-sized, and large enterprises in planning and implementing operational energy efficiency measures. The focus is on measures that are economically profitable from the point of view of the businesses, i.e., as a rule, with payback periods of less than three years. However, with statutory requirements for climate and resource protection constantly increasing, a holistic approach to recording, assessing, and implementing efficiency measures is important. Thus, changing the windows of a building may not be economically profitable over a short depreciation period, but when including the entire life cycle and the attendant use of resources over a longer time frame, it may be a particularly sustainable solution. Improved continuing professional development must not be limited to technological aspects but must explicitly include extended considerations of economic efficiency/profitability over a sufficiently long time. Such economic considerations should also include pricing of the side effects of new technological solutions.

Aspects of "Life Cycle Thinking" and the circular economy, along with all relevant connections, methodologies, and data, must increasingly and systematically be transmitted to multipliers in businesses via these networks. One example is the decarbonization network "dekarbN", which includes amongst others the methodology of Life Cycle Assessment as an important component: https://www.ffegmbh.de/kompetenzen/schulungen-und-kompetenzbildung/867-dekarbonisierungsnetzwerk-dekarbn

#### Life-long learning

As a result of rapid technological and social change, lifelong learning is becoming more and more important at all levels of education and training, from trades through technical colleges to universities. Training and degree courses alongside work, in trades and in universities, for continuing training in the aforementioned topics are becoming part of everyday working life.

While crossovers between trade apprenticeships, technical colleges and (technical) universities are becoming more transparent, this does not mean one-sided intellectual training. The distinctive nature of vocational training and its openness to interaction is a unique feature of Germany.

**4**

**Call for openness towards new technologies/ideas, demonstrate its significance, motivate trust in research and development by successful examples mirroring objectives of point (1).**

- Science and engineering must take responsibility for reaching the objectives mentioned in (1)
- Innovative and new technologies must be examined for their societal impact

Technology openness is not a value in itself, but necessary for creating playgrounds in research and industry for what is innovative and unexpected. It is a matter of not committing to one particular technology too soon, only to find later that alternative technological solutions could lead to better results.

Doubtlessly, the source of sustainable energy is, above all, the sun, which includes wind energy. Providing this energy for the needs of human society will give rise to many technological approaches in the coming years: Most concepts are based on converting solar energy into electricity and storing this in the form of hydrogen. But, of course, there is a variety of alternatives: Technology openness means giving these alternatives a chance [1].

Photovoltaics for electricity generation and electrolysis for generating hydrogen dominate the discussion today. Alternatively, electricity can also be generated by storing heat and using it in a steam power plant, which can thus also provide energy at night by storing thermal energy by day. The direct conversion of solar energy to hydrogen, e.g., in bioreactors, is also conceivable, perhaps even with better efficiency.

There are also numerous alternatives for converting electricity into heat or mechanical energy – heat pumps are significantly more efficient than immersion heaters; in vehicles, hydrogen can be converted directly into mechanical energy by internal combustion engines, or into electricity by fuel cells, with the electricity then converted into mechanical energy by electric motors.

For the transition period until sufficient amounts of green hydrogen are available, there is also a choice of alternatives that should be assessed without giving preference to a particular technology, e.g., generating hydrogen from methane by pyrolysis or processes for storing $CO_2$ in deep geological formations (CCS [2]).

For each alternative, the societal impact must also be considered. Thus, the land use of large solar power stations or the acceptance of wind farms is problematic in central Europe: Many concepts can only be implemented where sufficient land is available to allow an economical "energy harvest".

Finally, in order to avoid elements damaging to the climate for a transition or even extended period, nuclear power should also be considered, despite the German decision against this technology. Without doubt nuclear energy has one of the lowest greenhouse gas effects and countries neighboring Germany successfully rely on nuclear power to reduce their $CO_2$ emission. Reminding openness for new technologies there are promising concepts for next generation fission reactors which have an almost closed cycle with respect to the usage of fission materials and long living nuclear waste. With ITER Europe, America and the Pacific region engage for fusion as a future technology providing energy with a very low greenhouse gas impact.

**5**

**The regulatory framework must be shaped in such a way that those technologies prevail which have a positive impact on the objectives in (1) while remaining cost-efficient.**

- Sustainable pricing: External costs to be agreed on an international level/EU-ETS
- Green Dot ("Grüner Punkt") symbol and efficiency-labeling as a source of information
- Bottle deposit scheme
- Aim for internationally recognized/harmonized certification

The liberalization of energy and especially electricity markets is only very incomplete, like a lack of time and space dependent price signals or the proper internalization of environmental costs. The misallocation of money and measures is accordingly high and necessary incentives are missing. A simple regulation including these shortcomings is still missing. While a number of possible steps are listed below, it has to be clear that this is still an active subject of research, and an undisputed approach is still not developed.

Important keys to optimizing electricity supply toward a sustainable circular economy are:

- Recording and pricing in all costs and damage incurred in connection with generating, distributing, storing, and using energy;
- Apportioning these to the various customers along with taxes and other levies; and
- Splitting the price of electricity into fixed-rate, capacity-charge and unit-charge components.

The system of network charges and end-user levies (including exceptions/exemptions) is crucial for the extent to which an efficient energy supply is promoted or impeded. Sector coupling, referring to interconnecting (integrating) the energy consuming sectors – buildings (heating and cooling), transport, and industry – with the power producing sector introduces more complexity, as it increases the risk of cross-subsidies and of competitive situations that are no longer technology-neutral. An example of this is subsidizing the consumption of electricity generated by the consumers themselves, which makes heating water using immersion heaters more attractive, thus displacing more energy-efficient heat pumps. Would it not be better to try and have an at least equal incentive for customers to feed their self-generated electricity into the grid, so as to use the same amount of electricity to power both their own and two or three other heat pumps, rather than just one immersion heater?

The above challenges inherent in the apportionment of costs may be illustrated using the example of the system of network charges: The advantage of a capacity-based fixed rate is that this would be more appropriate (the actual grid costs being dependent on the design output rather than the actual amount of energy transported) and the electricity market spread (in relative terms) would be more pronounced for the customer, such that, in turn, the balancing of generation and load would be shared by load matching on the part of the consumer, to an extent that would be economically reasonable. But the major disadvantage would then be lower unit prices for the electricity, by approx. 7 to 8 cents/kWh, hence a significantly lesser incentive to save electricity and thus less energy efficiency. The disadvantage of a unit-based apportionment of grid costs is that customers having their own electricity supply would no longer share in the financing of the electricity grid to the same extent (undermining solidarity). As a consequence, network charges (relative to the remaining amount of electricity obtained through the grid) will increase further, leading to increased costs for the other grid customers. But then, in the event of a long period without wind and daylight (dark doldrums) in

January, everyone would still want to connect to the grid for electricity. And it is such events that the grid needs to be designed for. This shows the dilemma involved in developing a sustainable energy supply.

From the point of view of grid operators, the different treatment of capital costs and operating costs is perceived as a problem of electricity grid regulation. This is also apparent in that intelligent and often low-investment and material-saving solutions seem less lucrative. Regulatory authorities, however, point out that the seemingly different treatment of costs does not have a significantly different effect on profitability in the long term. Nevertheless, experience shows that, in accordance with grid operators' perception and assessment, different technologies actually are utilized differently, with options appearing most economical to grid operators winning out over the most cost-effective ones. Thus, the regulation of incentives should be developed further in such a way that it takes better account of the reality of grid operators' investment decisions. A crucial fundamental issue in this context is whether supposed energy supply security really consists in enough equipment (power lines and transformers) being installed so that supply can be maintained without intelligence.

**6**

**Internationalizing energy supply in competition with local self-sufficiency must also always be aligned with the criteria in point (1).**

- Taking account of geographic and social conditions (availability of land, wind, solar radiation)

Europe is committed to a common market with market-liberal exchange of products and services implying the right of everyone to purchase its energy from wherever within this common market. To restrict this freedom contradicts European legislation and there appears no rational need to change this. The wealth of our societies acquired during the last 1½ centuries relies to a great extent on this free exchange of goods. With respect to a sustainable competition, it is of outmost importance to give a price ticket to the goods, which includes the environmental and social cost of those – as described in the previous chapters. To be provocative to make that clear: Bio-tomatoes grown in winter in Bavarian greenhouse are a local product near to the consumer, but it might well be those tomatoes coming from the South are cheaper because they produce in total less $CO_2$.

Because energy transition will have a major impact on society, it is important to be supported by citizens, and that citizens, businesses and municipalities take part in its implementation locally and so become part of the energy transition. Thus, decentralized or cellular approaches have to be considered, too. They may also offer a chance for new emerging technologies, thereby enhancing technology openness.

But it is unclear what decentralized or cellular means in detail. What degree of energy self-sufficiency does it involve? Is self-sufficiency to be achieved even at the level of capacity, i.e., with each unit (cell) considered always producing exactly the amount of electricity that it needs at a given point in time? What size of catchment area (local grid, substation grid, or high-voltage grid; put another way: town, county, or state level) is relevant for a cell? Can consumers and generation and storage plant operators in such a cell leave the cell at any time if, given their energy behavior or their capabilities, they could earn more and/or pay less elsewhere?

A focus on maximum internationalization of energy supply harbors the risk of useful local potentials being utilized less, people not being appropriately involved, and sustainability goals, in particular those in the social domain, not being met. With this in mind, creating a European or global internal market for energy to the greatest possible extent cannot be an end in itself.

On the other hand, a decentralized energy transition saving on grid expansion could become such a voluminous undertaking as to lead to significantly more generation plants and storage capacity, higher costs and greater losses of electricity in the end. It would also mean the availability, in principle, of sufficient land in each of the various regions of Germany to cover the local energy needs to the required extent. Biodiversity protection, countryside conservation, or lack of popular acceptance could be limiting factors, alongside a shortage in the supply of cost-effective renewable energies.

The tension between storage and grid expansion is illustrated by the geographical balance of fluctuating electricity generation from wind and solar energy. Figure 2 shows the simultaneity factor for different geographical extents using the example of wind power supply, i.e., the usability of stochastic balancing effects. While, on the regional level, maximum input peaks must be dealt with and input limits and storage needs must be set accordingly, the capacity peak is more than halved on the European level. Thus, there is minimal need for storage. Storage facilities are necessary for when there is a time lag between supply and demand. A higher demand as a result of less grid expansion limits the market supply, leading to higher prices. Furthermore, storage facilities for avoiding grid expansion lead to a greater need for investment overall and thus to higher electricity costs. Storage facilities for balancing the daily cycle would be insufficient for that, again leading to increased costs. In addition, temporary storage involves a greater loss of electricity (compared to electricity transportation). This in turn requires more generation plants, which are basically only needed to compensate for the loss of electricity in storage. Overall, the consumption of resources also increases.

For expanding the grid, in contrast, there is a need of materials and issues with acceptance by the population. Another problem is that it becomes easier for one supplier to become dominant and so to utilize its market power, thereby in turn limiting citizens' participation and value creation locally. This dominance of a monopoly provider must also be avoided when internationalizing energy supply.

Thus, this example shows the complexity to be navigated in balancing grid expansion (for internationalization) and decentralization.

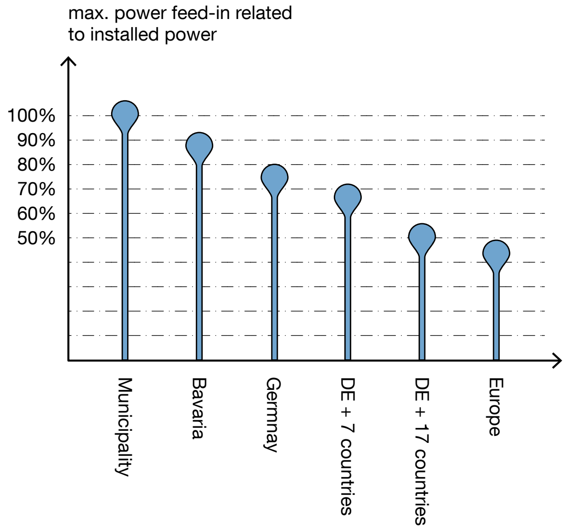


Figure 2: Simultaneity factor of wind power feed-in through spatial equalization, Sources: VGB, own analyses

Given a meaningful pricing and levying system and regulatory framework strictly adhering to the sustainability goals in point (1), a reasonable extent of endogenous energy supply should take shape for each grid user, each urban district, each town or region. With conditions for the accepted, technologically feasible, and economical use of renewable energies differing for each individual and in each region, different degrees of self-sufficiency will arise accordingly. It remains important for each grid user to be able to contribute to balancing generation and load and to supporting the grid, and to be incentivized to do so where this can meet the sustainability goals.

In Germany, and also in Northern Europe, self-sufficiency in energy supply cannot be achieved given the current state of the art or can only be achieved under grave objections from society and with the attendant destruction of nature.

In future, approx. 70 % of Germany's energy demand will continue to have to be imported. The import of energy in the form of sustainably generated electricity, hydrogen, or derivatives instead of oil and natural gas opens up trade opportunities for other countries and may require supporting investments in, and the political stability of, regions with high levels of solar radiation such as North Africa or the Arabian Peninsula.

It is a political principle in Germany to exclude nuclear power as a source of energy. Nuclear power is one of the most climate-neutral technologies, and it is safe. The decision made by other societies/countries to use it for a sustainable energy supply must be respected, and its use must be considered in the conception of the global networking of various energy sources – including for Germany.

**Policy recommendation**

Local self-sufficiency in energy supply is limited by:

(i) Inefficiency, with unequal solar radiation not being utilized;
(ii) Limited economic viability due to fragmentation, unnecessary redundancy of facilities;
(iii) Social imbalance, as it prevents others from creating economic value;
(iv) Unnecessary use of resources, thus having a negative environmental impact.

**7**

**Strengthening a circular economy of energy and materials.**

- E. g., use of waste heat and circular flow of heat
- E. g., decreased demand for energy in raw materials industry by more recycling/lightweight construction/longer life cycles

**Interlinkages of circular approaches and energy technologies**

As shown in Figure 3, there are different types of circular approaches in all life cycle phases of a product or technology. Apart from resource recovery through recycling, the extension of the product's/technology's lifetime can also be a means of optimizing resource use. Additionally, in the use phase, sharing concepts can be an option for increasing the utilization of resources. However, a CE still requires the supply of resources in the form of energy and materials. In this context, the use of renewables and efficiency measures are important approaches to establishing a sustainable CE.

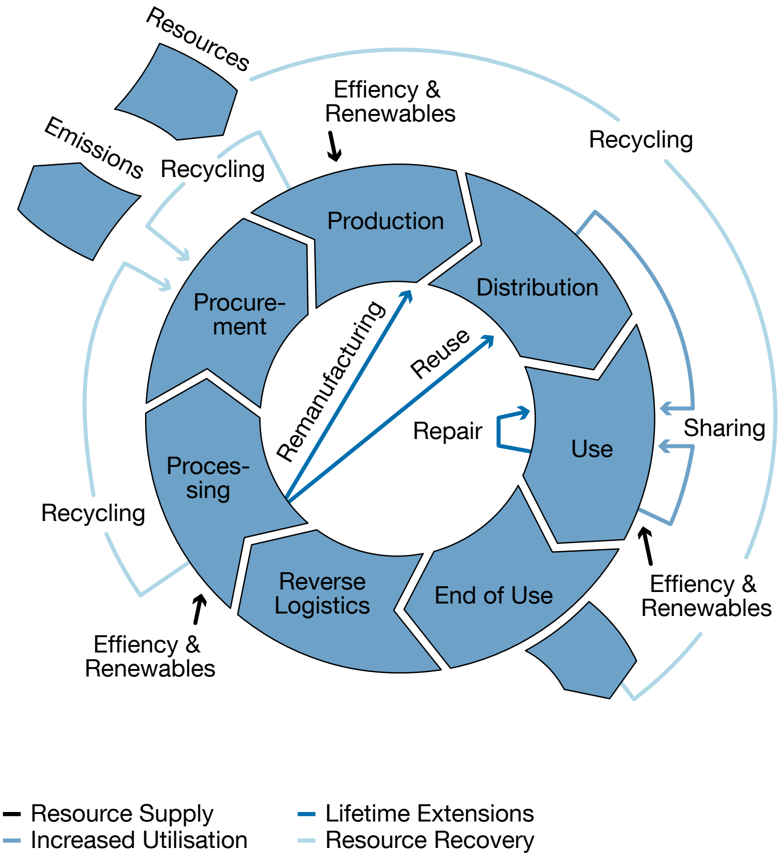


Figure 3: Overview and classification of approaches from the circular economy in different life cycle phases
(own illustration based on Accenture 2014 [1])

For a sustainable CE, the energy and materials needed in all life cycle phases must be obtained from renewable sources. Since even renewable resources are not available in unlimited quantities, given restrictions on, e.g., land use and capital, energy and materials must be used very efficiently in a CE. Some of the materials used for the technologies required for a renewable supply and efficient use of energy are associated with significant environmental impacts and/or supply risks. Therefore, to reduce environmental impacts and resource risks, the materials used in renewable and energy-efficient technologies must be managed in cycles. Thus, on the one hand, innovative energy technologies, on both the supply side and the application side, are required to establish a sustainable CE. On the other hand, a CE is the key to providing these technologies in a sustainable way.

It must be noted that 100 % recycling is not the best solution in every case, as recycling also always requires energy input. This can be unreasonably high if even the final few percent of a material are to be recycled. Also, prolonging life cycles does not only come with advantages, either. If this occurs, say, during a transition period in which the technology concerned is still in the process of being improved, prolonging its life may be counterproductive if this involves locking up valuable resources in the system. Take the example of electric car batteries: These batteries will contain less and less cobalt in future. Now if old batteries with a high cobalt content continue to be used for a long time, the cobalt is not then available for producing new batteries with a lower cobalt content [2].

Other relevant approaches at this point are Design for Reuse and Design for Recycling. Their aim is to design technologies so that they can be repaired quickly (e.g., modular design) and/or recycled easily (e.g., not using composites that are difficult to separate). This has to be kept in mind, in particular, in lightweight construction, so that any newly developed (composite) materials are easily recyclable.

The previous remark implies that when assessing technologies in a CE, for example with the Life Cycle Assessment (LCA) method, a prospective view is required to consider future developments. The application of circular approaches needs to be considered since they can strongly influence a technology's environmental impact. The growing share of renewable energy systems for example leads to a reduced impact of energy use in a CE and thus a changing basis for evaluation.

**Example: Heat recycling**

One variant of the circular economy that has received little attention to date is heat recycling, be it by means of high-temperature heat pumps up to around 140°C (150°C), by heat transformation up to around 250°C, or by using waste heat with additional firing at temperatures of up to >1,000°C. This also applies to batch processes with fluctuating waste heat streams, which could be used when needed, uniformly or intermittently, by means of suitable water, latent or chemical storage and recuperators or regenerators. This in-house recycling of heat streams is not currently much practiced.

Many of the technological opportunities mentioned are profitable given current energy prices and will be even more so with rising $CO_2$ levies in the coming years.

**Economic assessment and obstacles to utilizing potential**

Although heat recycling is often profitable, it is only used by a more or less small proportion of the sectors and businesses concerned. There are many reasons for this, which include:

- 80 % of businesses take decisions on energy efficiency according to the level of risk over the capital payback time (usually less than three years, despite most investments having life cycles of between 10 and 20 years); only few consider profitability based on cash value or the internal rate of return.
- Energy-efficient production frequently has positive side effects which are not considered or monetized by businesses and therefore not included in profitability assessments [3].
- Consulting engineers, energy managers, developers, and production engineers are often not or insufficiently aware of many opportunities for improvement by using heat recycling. There may also be insufficient space for retrofitting the equipment.
- Statutory rules, regulations, or out-of-date technical standards are further obstacles to implementing innovative solutions with energy-efficient heat recycling.

**Policy recommendation**

In order to realize the significant potentials of heat recycling and the attendant energy savings, as well as recycling waste heat with an increase in temperature, there is a need for improving/supplementing the continuing professional development of the above-named target groups, an extended profitability calculation which includes both the financial return and the additional side effects, and for removing obstacles caused by statutory or official regulations.

**8**

**Transition technologies are necessary as a step toward the objectives and in offering an opportunity to advance carbon-neutral technologies. Possible technological lock-ins need to be considered.**

- E. g., colors of hydrogen

**Colors of hydrogen**

The colors of hydrogen in Figure 4 identify the processes of generating hydrogen from available primary energy sources. Each of the color-coded processes is distinguished by its efficiency, carbon footprint, and Green-House-Gas profile when using the primary energy source to generate hydrogen. It is particularly apparent how the trend toward electrification through renewable energies with “clean hydrogen” will also affect, in particular, hydrogen-based chemical industry.

1. Reforming of fossil fuels is only sustainable with carbon capture.
2. Electrolysis as a future key technology when using renewable energy.
3. Pyrolysis as an alternative transition technology while using natural gas for carbon-neutral hydrogen generation.

Hydrogen generation by reforming is currently the main source of $CO_2$ emissions in industrial applications globally. Its substitution by electrolysis will necessitate the development of a new infrastructure (renewable energy converters, electricity distribution networks, energy storage facilities for renewable energies).

The great demand for these new infrastructure elements must be examined for delays caused by production bottlenecks for the components and obstacles to their market launch, with economies of scale only becoming effective later for competitive pricing. Additional bottlenecks are to be expected as a result of the shortened deadlines for achieving climate targets. In particular, there is a lack of mandatory national changeover programs, international certification agreements, and market-driven mechanisms for financing this transition to electrical hydrogen generation.

Pyrolysis, by largely utilizing the existing natural gas infrastructure, could be a transition technology for achieving the climate targets until a completely hydrogen-based energy industry is started up [1].

## Colors of Hydrogen

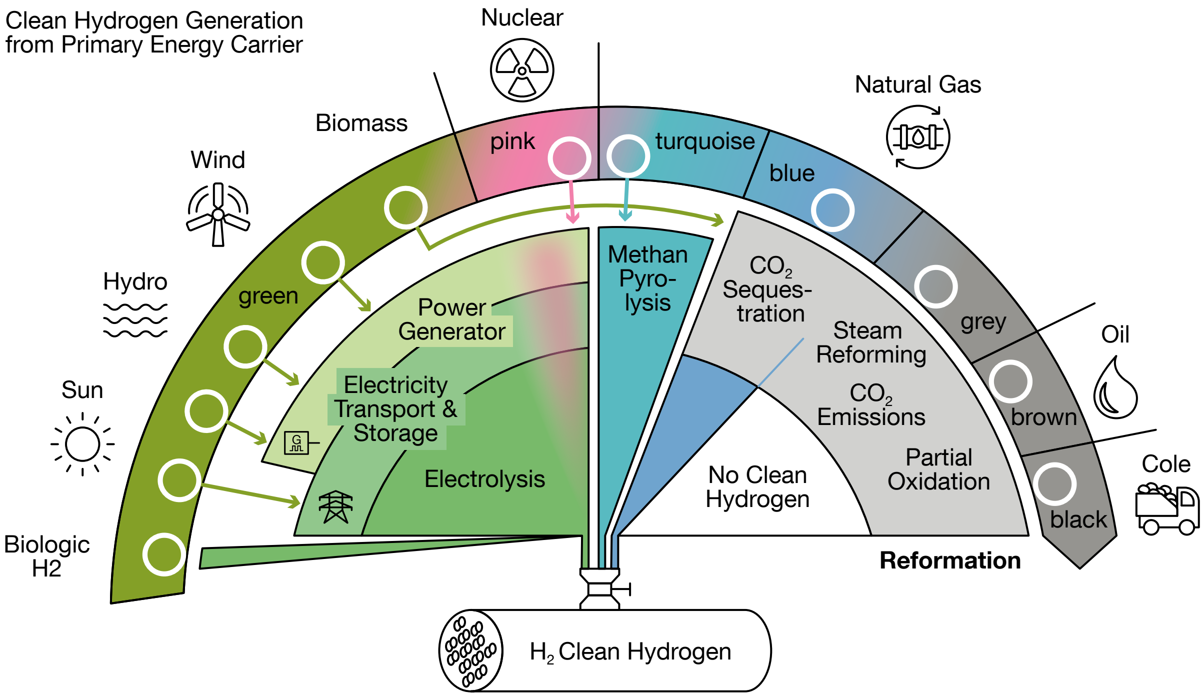


Figure 4: The colors of Hydrogen

# II.2.3. References


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# II.3. Economic Theory and Practice

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# II.3.1. Recommendations for Action – Working Group III

**1** All actors should engage in the Circular Economy (CE) through multiple circular strategies and their combinations with the goal to achieve the most sustainable value.

**2** CE requires an integrated design of resources, products, and socio-technical systems.

**3** New policy frameworks are required in order to enable a sustainable production and consumption system for all stakeholders.

**4** Businesses need to develop and evaluate new circular business models together with their users in order to facilitate sustainable value creation and capture.

**5** A shift in the concepts of ownership based on product-as-a-service business models is a key driver to integrate CE considerations into the business processes.

**6** For a successful transformation to a CE, we need collaboration across actors and stages of the value cycle. To gain experience we need to experiment with these forms of CE.

**7** We need tailored communication instruments for the market and customers to communicate circular characteristics of products and systems.

**8** Innovative thinking revised innovation processes are needed to pursue the vision of the CE and infrastructures and related technologies have to be further developed.

**9** We need new quantitative methods to make the holistic aspects of the Circular Economy more visible, quantifiable and predictive (short, medium and long term).

**10** Since CE alone cannot solve all sustainability challenges, it has to be complemented with further sustainability concepts.

**11** All these 10 messages and recommendations need to be integrated into curricula and training programmes to deploy CE into theory and practice and accelerate the broader sustainability transition.

## Annotation

The following texts of Part II.3. have been developed on the basis of contributions from and discussions with the participants of the Working Group “Economic Theory and Practice”.

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# II.3.2. Explanations

**1**

**All actors should engage in the Circular Economy (CE) through multiple circular strategies and their combinations with the goal to achieve the most sustainable value.**

The circular economy (CE) covers two types of cycles: Technical cycles aim at prolonging product, component, or material lifetimes through maintenance, reuse, refurbishing/remanufacturing, and recycling. They aim at keeping products in life as long as possible by using the smallest, most environmentally preferable loops. According to the "inertia" principle, "Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured." (Stahel 2010, p. 195). Second, biological cycles, are about using biogenic resources for materials and products and – after their technical cycling or cascaded use (e.g., using fibres from clothing subsequently as insulation material) – subsequently returning them to soil via intermediate processes of anaerobic digestion (e.g., biogas plants), composting, or complete biodegradation in the biosphere (Figure 1).

The current discourse and practice is often dominated by isolated strategies, particularly recycling which is often the strategy with the lowest environmental benefit among technical cycles. The move from lower-level material circulation to higher-level strategies of product integrity through maintenance, repair and remanufacturing is crucial to advance the CE and can be supported by new business models. Moreover, rather than focusing on a circular strategy in isolation (e.g., recycling), the main potential of the circular economy lies in combing them in circular strategy configurations for maximizing the productivity of products and materials over several life cycles (for instance, in the remanufacturing process of products, broken parts are repaired and worn materials are feed into recycling processes). Implementing strategy configurations and related product designs often faces design trade-offs as, for instance, products characterised by durability enable their reuse in additional use cycles but may be more difficult to disassemble and recycle. Due to the multi-criteria nature of sustainability, where advances regarding one criterion may lead to disadvantages regarding another (Fröhling et al. 2013), it is of central importance to align circular strategies and their combinations with overall sustainability goals.

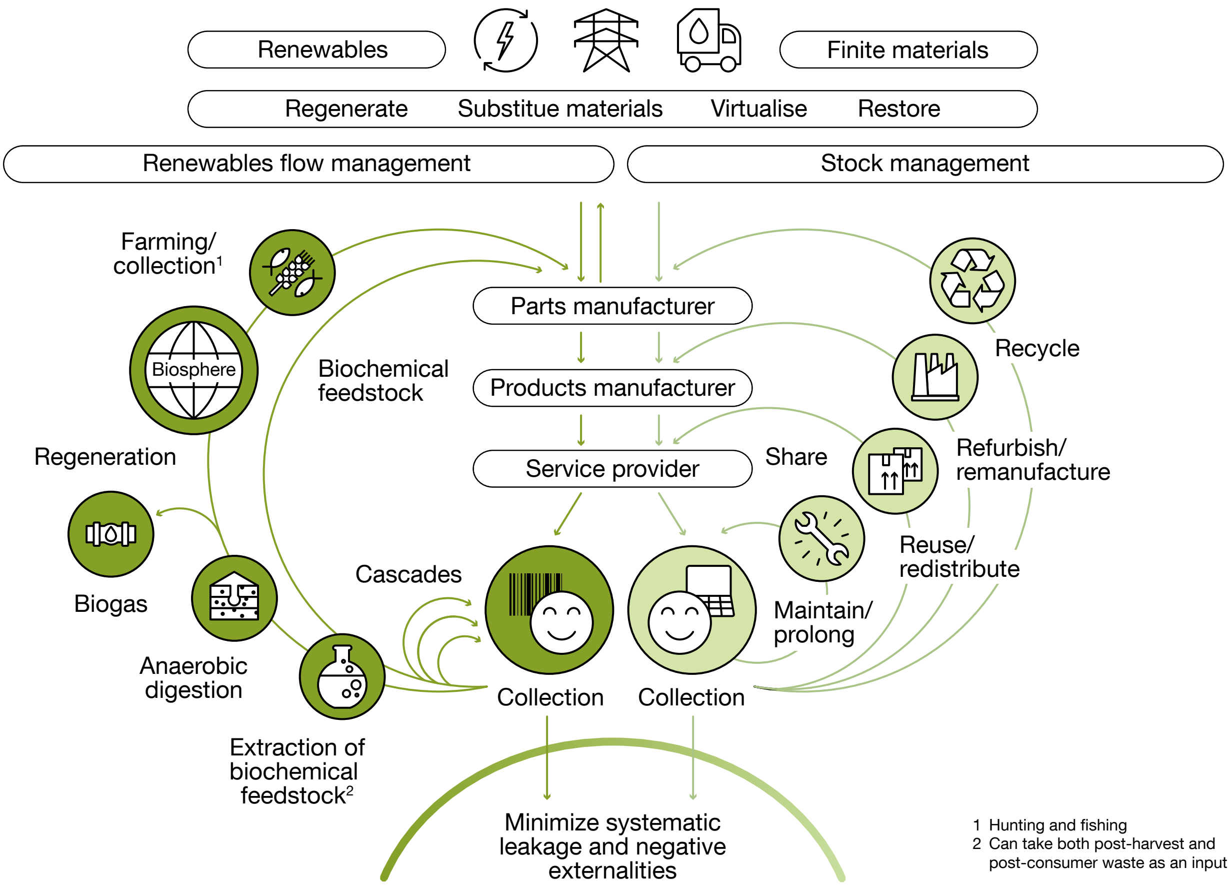


Figure 1: Circular Economy consisting of biological and technical cycles

Source: Ellen MacArthur Foundation (2013), p.24)

**2**

**CE requires an integrated design of resources, products, and socio-technical systems.**

The circular economy takes a systems approach covering micro, meso, and macro levels (Figure 2). Transitioning from a linear to a circular economy requires design changes on every level in order to be successful.

- On the micro level, individual firms and their customers need to change. Firms need to adapt their products and services and related business models, processes, and organisational structures (e. g. repairable products and related repair offerings in the market) and customers have to embrace these new offerings and change their behaviour to achieve circulation (e. g. bringing products back for repair and paying for it).
- On the meso level, firms have to collaborate in partnerships and networks, usually across sectors, in order to create circular systems. For instance, producers have to collaborate with the waste management sector to organise products and material take-back. This also requires advances in public and private infrastructures to enable such circulation (e. g., collection infrastructures for the reuse of products need to be redesigned in a way that returned products are not damaged).
- On the macro level, the design of conducive policy frameworks on the European, national and state-Level are key to achieve circularity.

However, an integrated view of these scales is needed in order to avoid problem shifts among stakeholders, life cycle phases and levels of consideration. As circulation depends on the contribution of human actors, particularly users of products and services, the design of these systems should be human centred and behavioural aspects (and related behavioural economics) should be considered as a central point. As in a linear economy often little attention was paid to what customers do with products, circular design strategies have focused mostly on the physical aspects of closing material cycles and so far little attention has been paid to behavioural aspects. These should however be considered as well in the design phase (Westling et al. 2018).

The desired circular system can be considered a moving target, because new technologies, industry practices, behavioural practices, and cultural norms emerge. Against this background, the temporal dynamics and evolutionary processes as known from socio-technical transition sciences are crucial.

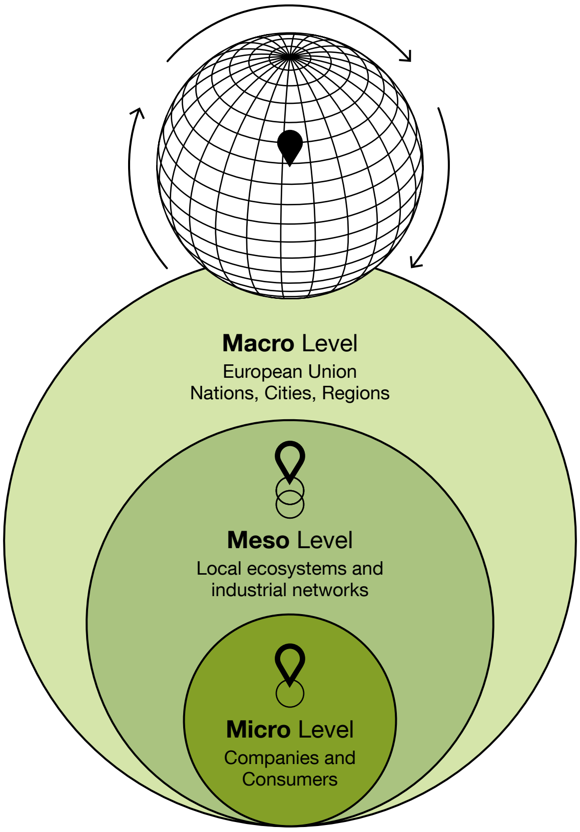


Figure 2: A systems approach to the Circular Economy
Source: Vanhamaki, S., et al. (2019)

**3**

**New policy frameworks are required in order to enable a sustainable production and consumption system for all stakeholders.**

Economic actors currently often do not have the incentive to act towards a CE. For instance, producers seldom invest in organising the take-back, reuse, and remarketing of their products and the waste management sector is not always interested in a reduction of waste. A circular economy cannot be achieved by market forces alone, particularly when the market framework does not fully internalise external costs. Hence, the necessary change here requires comprehensive policy frameworks that make use of the power of the market economy, but with revised rules.

A key element of the systems approach to a circular economy is therefore the design of conducive policy frameworks. This includes both the creation of new incentives for and the removal of existing barriers to a circular economy. Successful examples from the Netherlands and some Scandinavian countries show that it is possible to set and reach ambitious targets for a circular economy and revise the policy framework accordingly. This includes a reform of fiscal measures (e. g., through tax reforms), business support schemes, regulatory frameworks including command-and-control measures, facilitating collaboration platforms, public procurement, as well as education, information and awareness measures (Figure 3).

As value creation takes mostly place in international competitive markets and multiple interlinked international value chains, a consistent framework on the European level – covering the internal market and the imports to the EU – is needed to create a level playing field and promote and secure sustainable businesses (Figure 3).

| **Policy intervention types** | **Examples** |
|---|---|
| Education, information and awareness | Integration of circular economy/systems thinking into school and university curricula |
| | Public communication and information campaigns |
| Collaboration platforms | Public-private partnerships with businesses at national, regional and city level |
| | Encouragement of voluntary industry collaboration platforms, encouraging value-chain an cross-sectoral initiatives and information sharing |
| | R&D programmes in the fields of, for example, material sciences and biosystems |
| Business support schemes | Financial support to business, for example direct subsidies of capital, financial guarantees |
| | Technical support, advisory, training and demonstration of best practices to business |
| Public procurement and infrastructure | Public procurement |
| | Public investment in infrastructure |
| Regulatory frameworks | Government (sector) strategy and associated targets on resources productivity and circular economy |
| | Product regulations, including design, extended warranties and product passports |
| | Waste regulations, including collection and treatment standards and targets, the definition of waste, extended producer responsibility and take-back systems |
| | Industry, consumer, competition and trade regulations, for example on food safety |
| | Accounting, reporting and financial regulations including accounting for natural capital and resources, and the fiduciary duty on investors and managers |
| FISCAL Frameworks | VAT or exercise duty reductions for circularity products and services |
| | Tax shift from labour to resources |

Figure 3: Six policy intervention types, Source: EMF (2015), p.47)

**4**

**Businesses need to develop and evaluate new circular business models together with their users in order to facilitate sustainable value creation and capture.**

A circular economy cannot be achieved by simply introducing new products or processes in isolation. Often existing business models are locked-in to a linear approach hindering the success of circular economy-related innovation. For instance, product repair may be commercially unsuccessful because the repair service is poorly designed or because the business model's value proposition to the customer, sales channels, and revenue streams are optimized for the growth in sales of new products. The redesign of the business model's value proposition, value delivery, and value capture is therefore essential and must include both product and (after sales) service components (CEID 2021a, CEID 2022b). This requires going beyond the focal actor's business model and considering all partners in a business model ecosystem and their alignment towards delivering circular offerings and truly closing the loops. The actual success of circularity can only be measured – and potential rebound effects can be prevented – when the focus on the individual firm is transcended towards a perspective of the whole (partner) ecosystem.

**5**

**A shift in the concepts of ownership based on product-as-a-service business models is a key driver to integrate CE considerations into the business processes.**

In traditional product sales, producers hand over products and liability to customers. Function guarantees provide customers limited access to a manufacturer's operation and maintenance skills, which may contribute to prolonging product lifetimes to some extent. In the development of more circular business models, however, ownership becomes crucial. When producers or third-party fleet managers keep ownership and offer these products as a service to customers, it is much easier for these providers to implement circular strategies. For instance, while in product sales producers depend on the customer to return products voluntarily, in a leasing business model product return is a mandatory part of the contract. When ownership and liability for products are retained by manufacturers ("selling performance") or third-party providers ("goods-as-services"), they bear the risks and the costs for the products and therefore have an intrinsic motivation to reduce these (Figure 4). In general, such use and results-oriented service business models therefore have a higher potential for reducing negative environmental impacts and, additionally, for avoiding structural waste like unused resources (Figure 4).

While these business models have been pioneered for providing products, particularly investment goods, in the future they also need to be applied to other levels such as the material level as represented by the "molecules-as-a-service" or "materials-as-a-service" business model. Digitalization is an important enabler for such service-oriented business models, because it allows for the necessary data exchange between the user and the service provider (CEID 2021a, CEID 2022b).

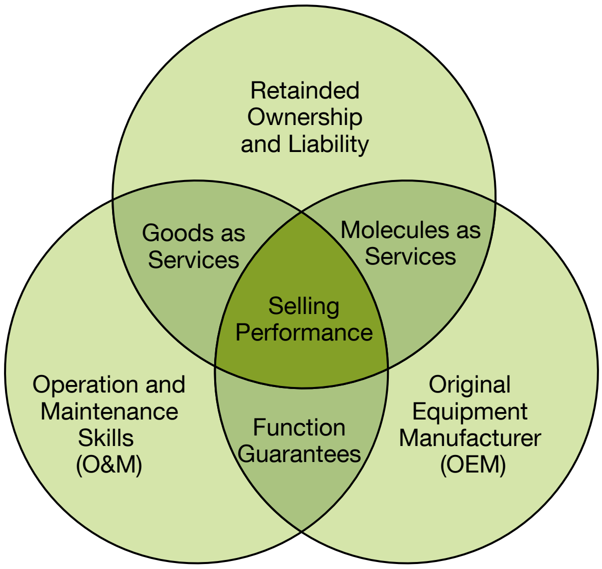


Figure 4: Circular business models from a servitisation perspective
Source: Stahel (2019), p. 67

**6**

**For a successful transformation to a CE, we need collaboration across actors and stages of the value cycle. To gain experience we need to experiment with these forms of CE.**

Compared to sustainability in more general, the demands of circular products, services, and business model ecosystems significantly increase the demand for collaboration and co-creation. To redesign resources, products, and socio-technical systems (cf. No. 2) for circularity, the design has to be coordinated across functions in the organisation and actors in the value cycle. For instance, the design for recycling of a packaging must be compatible with the waste management and recycling infrastructure (Hansen and Schmitt, 2021). Knowledge brokers from the domain of sustainability and circularity, such as NGOs, also become important players, as companies usually do not have the necessary internal expertise. This calls for a more open innovation scheme to facilitate the innovation processes. To actually close the cycles, actors also need collaboration because the physical resources (products, components, or materials) need to be transported, processed, and reintroduced to the market. This requires going beyond the focal actor's business model and considering all partners in a business model ecosystem (Figure 5). The entire ecosystem must be aligned towards delivering circular offerings and truly closing the loops. Co-creation with users becomes also relevant because user behaviour is key in product return.

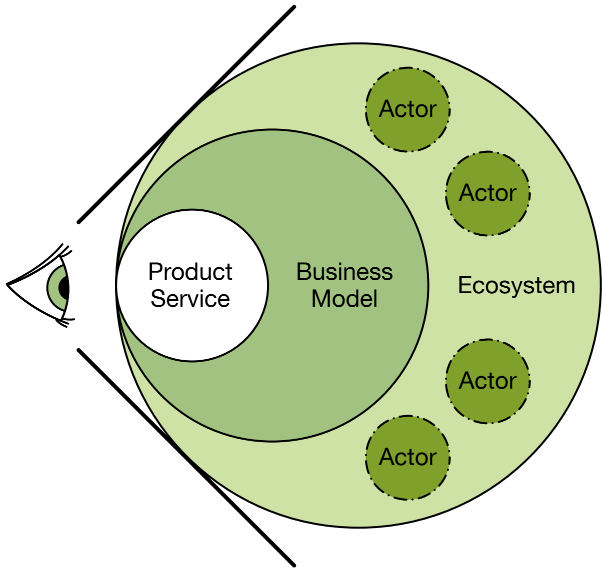


Figure 5: Collaboration across the value cycle in business model ecosystems, Source: Konietzko et al. (2020)

7

**We need tailored communication instruments for the market and customers to communicate circular characteristics of products and systems.**

A broad variety of communication instruments for circular product and service offerings, and related processes, exist today in the market (Figure 6). This includes eco-labels for materials (e.g. design-for-recycling; recycled or bio-based content), for circular products (e.g. cradle to cradle), for processes (e.g. remanufacturing according to ANSI RIC001.1-2016), and organisations more broadly (e.g. ISO/TC323 Circular Economy standard). In addition, many methods exist to communicate results of sustainability assessments and making them more intuitive (Fröhling and Hiete 2020). Existing communication instruments have to be further diffused and, where necessary, newly developed. This enables the communication with customers and further market participants in an easy comprehensible, transparent, and user-centred way so that they can take informed decisions. Transparency and digital technologies (e.g. smartphone-based retrieval of product characteristics) are key enabling factors to engage customers with circular offerings.

8

**Innovative thinking revised innovation processes are needed to pursue the vision of the CE and infrastructures and related technologies have to be further developed.**

The transition towards a CE requires innovative thinking on all levels of the system. To leverage innovation capabilities within the system for the CE, firms need to redesign their technology management and broader innovation processes. Only if research and development strategies explicitly address circularity and related checkpoints include actual assessments of circularity and sustainability, the innovation outcomes will contribute to the intended future circular economic system. This is influenced by the regulative and policy framework, the available resources and the interaction with stakeholders (Figure 7).

In order to facilitate such firm-level innovation of circular products and services, more investments – both from industry and public entities – into the circular system are necessary, particularly into the technological and non-technological infrastructures. For instance, the adoption of new technologies for image processing, sorting, and separation in the public or private collection systems plays an important role for closing material cycles. Thereby, technological choice should be based on clear environmental benefit (and its environmental potential in a redesigned circular system), not circularity per se. A central obstacle on micro, meso, and macro level can be technological lock-in, hindering a continuous improvement and further development of technologies and processes.

Digitalization can play an enabling role in overcoming some of these obstacles, facilitate collaboration across value cycles, and thereby drive closed loop-solutions and related business models (CEID, 2021b, Alcayaga et al., 2019).

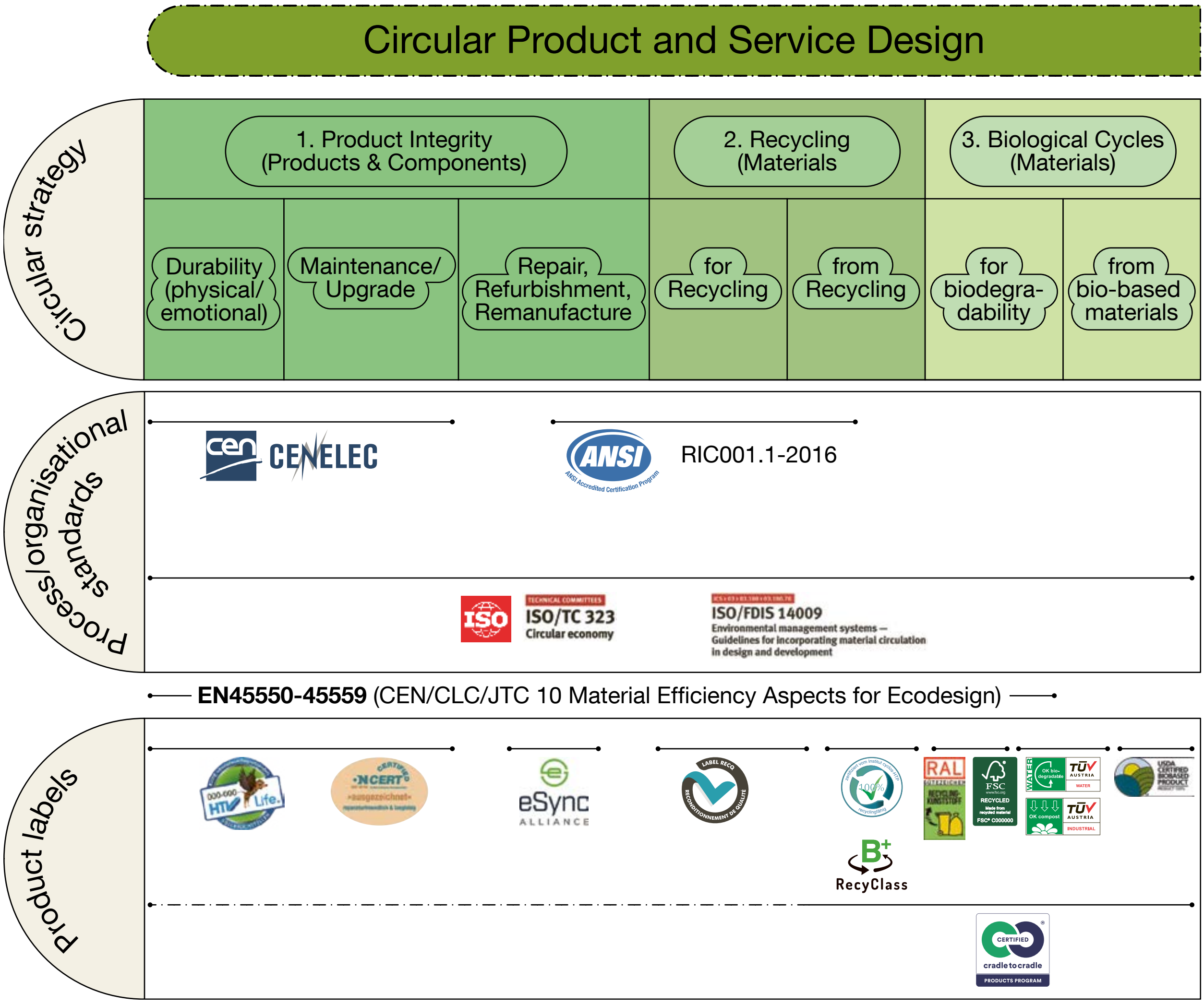


Figure 6: Exemplary communication instruments for materials, products, processes and organisations

Source: based on Hansen et al. (2020), p.10

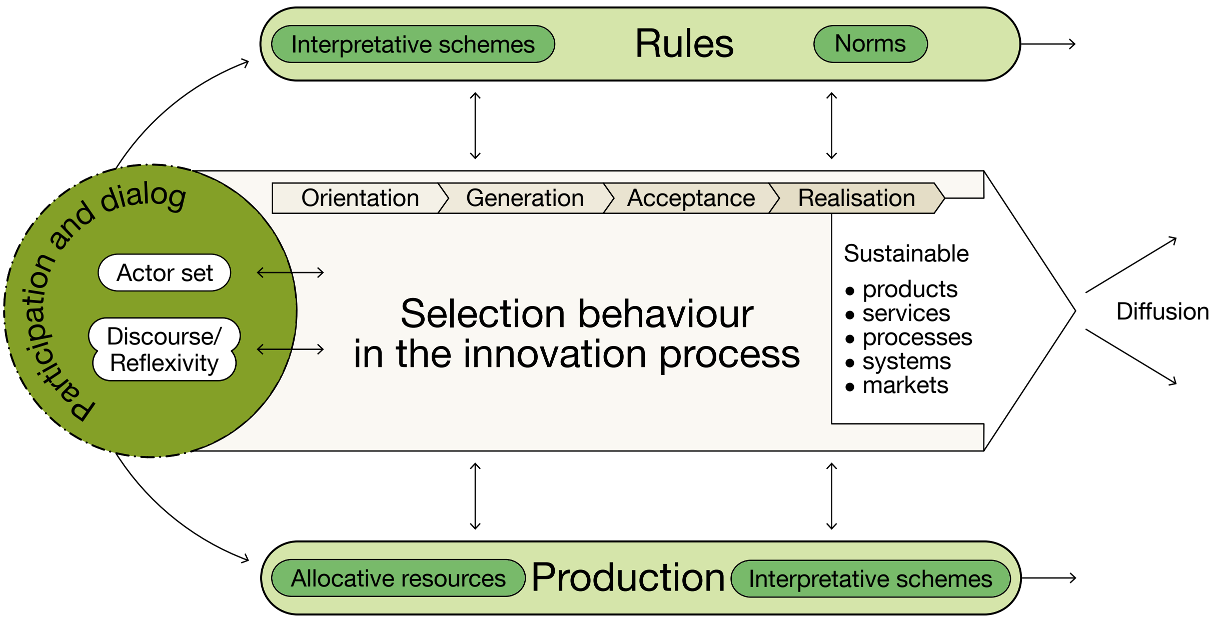


Figure 7: Structural policy approaches for a change of selection mechanisms

Source: Fichter, K., & Paech, N. (2004)

**9**

**We need new quantitative methods to make the holistic aspects of the Circular Economy more visible, quantifiable and predictive (short, medium and long-term).**

Existing methods from the broader field of sustainability management, life-cycle assessment, and economics often do not account for the specifics of the circular economy, in particular, the need for considering more advanced configurations of technical and biological cycles and combinations thereof. Organisations and nations aiming at advancing the circular economy need measurable indicators to evaluate their success towards reaching circularity and, relatedly, how this drives sustainability performance (Figure 8). This involves indicators and methods for the micro (i.e. organisations), meso (i.e. local ecosystems, value chains, and industrial networks) and the macro (i.e. nations) scale in a coherent and consistent framework. A challenge for the new methods is to capture change as early as in the innovation processes, considering the entire cycle including the behavior or the actors in the system (e.g. users), and capturing the dynamics of the overall transformation processes.

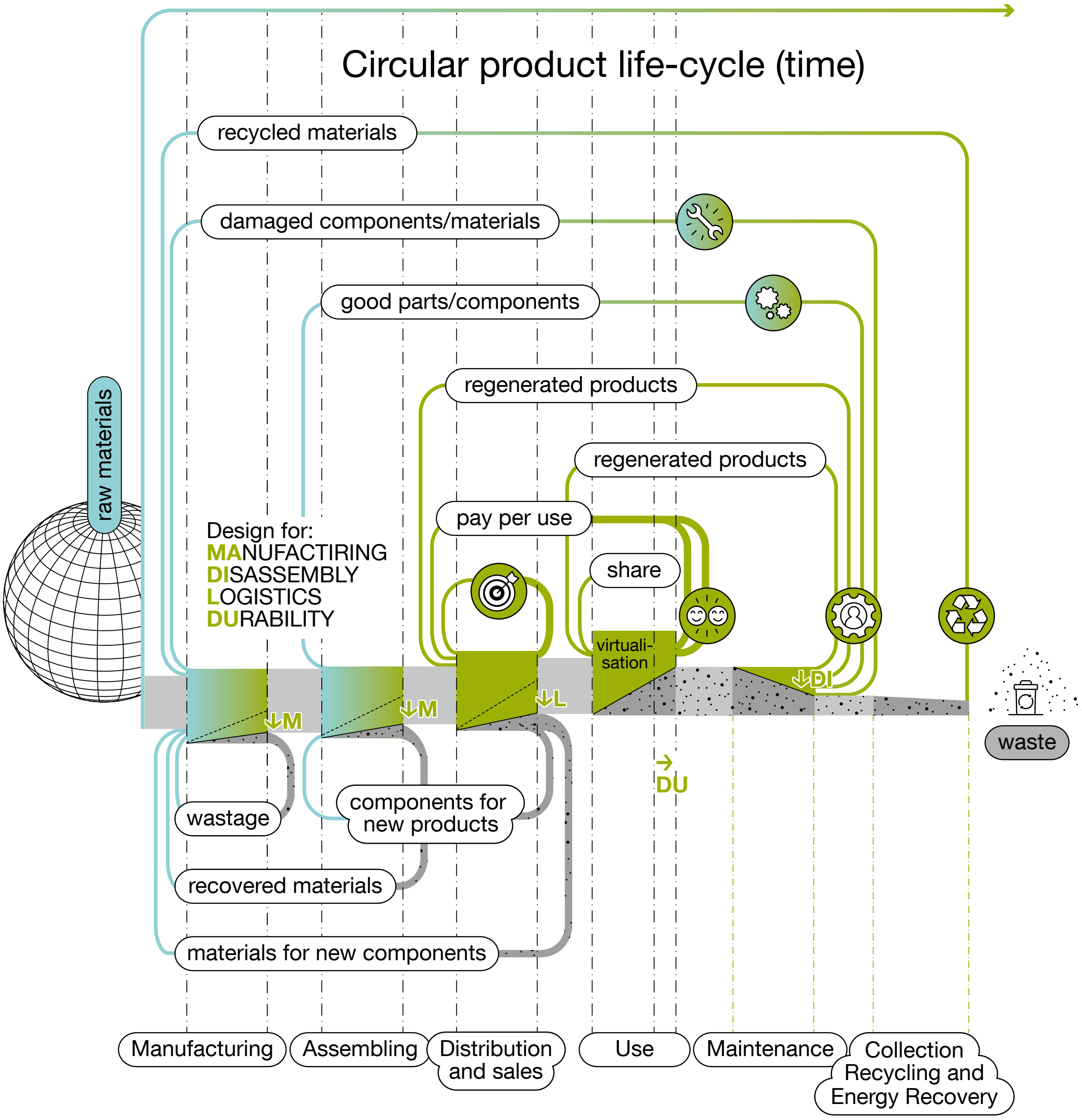


Figure 8: Exemplary new quantitative visualisation method for the product life-cycle and circular strategy configurations
Source: Bianchini et al. (2019), p.22

**10**

**Since CE alone cannot solve all sustainability challenges, it has to be complemented with further sustainability concepts.**

We are confident that, in the upcoming years, the circular economy will play a major – if not the main – role for transitioning industry and society at large towards sustainable development. But the circular economy is not a panacea for sustainability challenges. Cycling of materials, components and products is not possible in unlimited ways. For instance, many materials often lose some quality over each cycle and products cannot be repaired forever. Moreover, despite the turn to circular offerings, ever increasing wants and desires in society may thwart achieving an absolute reduction of resource consumption. While even a strong interpretation of CE – as it was considered in this workshop – has the mentioned limits, practice shows many not that rigourous approaches ("weak circularity") (Johannsen and Henriksson, 2020). Among these and further aspects, CE is also criticized for neglecting previous and other knowledge (Corvellec et al., 2021). CE frameworks therefore have to be complemented by other sustainability strategies and policies such as sufficiency (reducing demand), renewable energy (eliminating $CO_2$ from energy consumption), and broader environmental policies in order to make economies and societies fully consistent with sustainable development. Only in such a concerted approach it is possible to address and achieve the sustainability goals with their different environmental, economic and societal layers and international and responsible partnerships (Figure 9).

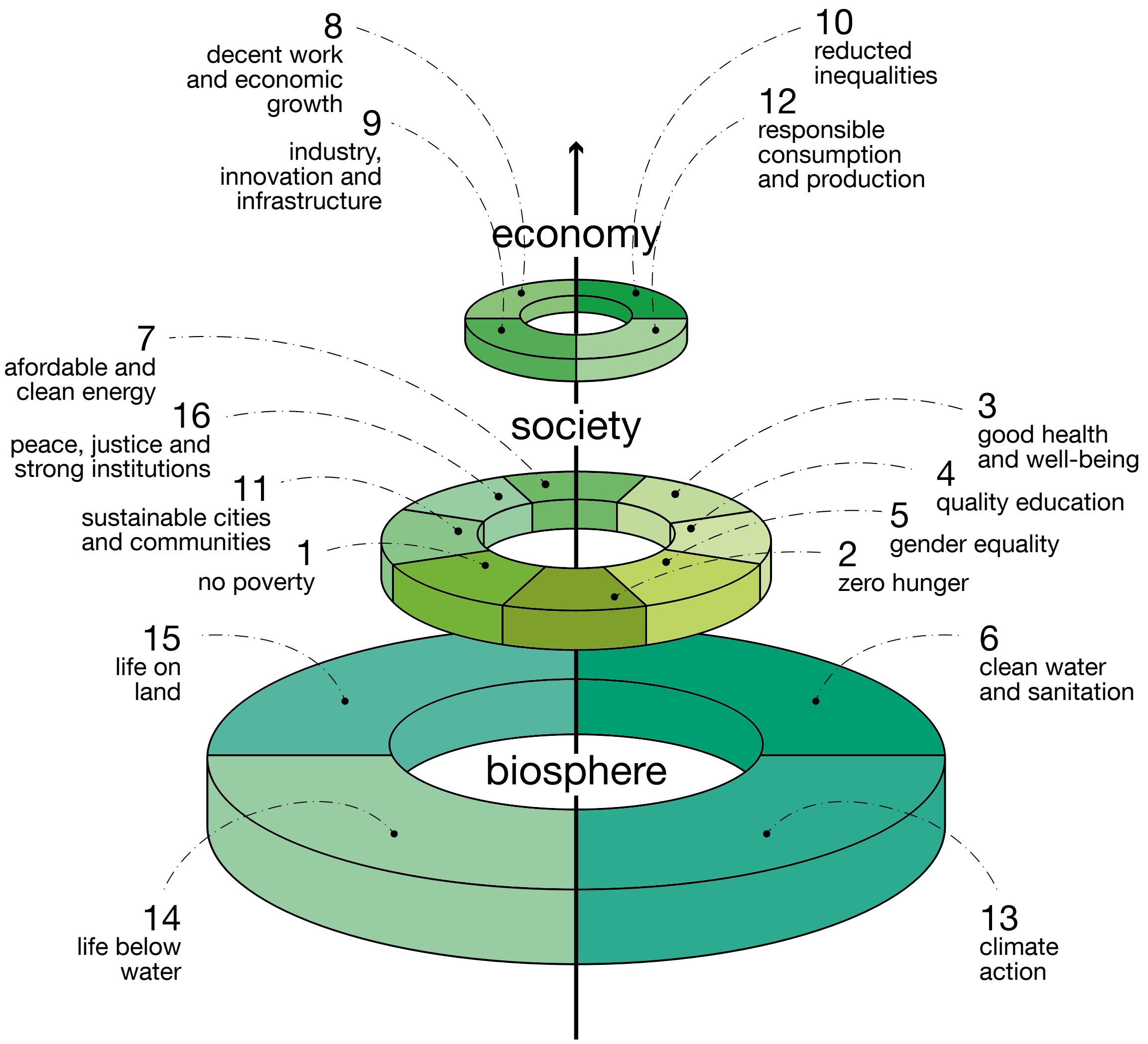


Figure 9: Sustainability dimensions addressed by the 17 SDGs
Source: Stockholm Resilience Center (2016)

**11**

**All these 10 messages and recommendations need to be integrated into curricula and training programmes to deploy CE into theory and practice and accelerate the broader sustainability transition.**

In today's societies and economies characterised by swift technological and environmental change, educational and training programmes need to advance life-long learning. Particularly the transition to a circular economy and sustainable societies requires an educational approach. Universities are in a key position to advance this agenda and have the responsibility to address these critical knowledge and tools to individuals in their diverse stages of learning, including Bachelor, Master, Doctorate, Executive, and further certificate programmes (Figure 10).

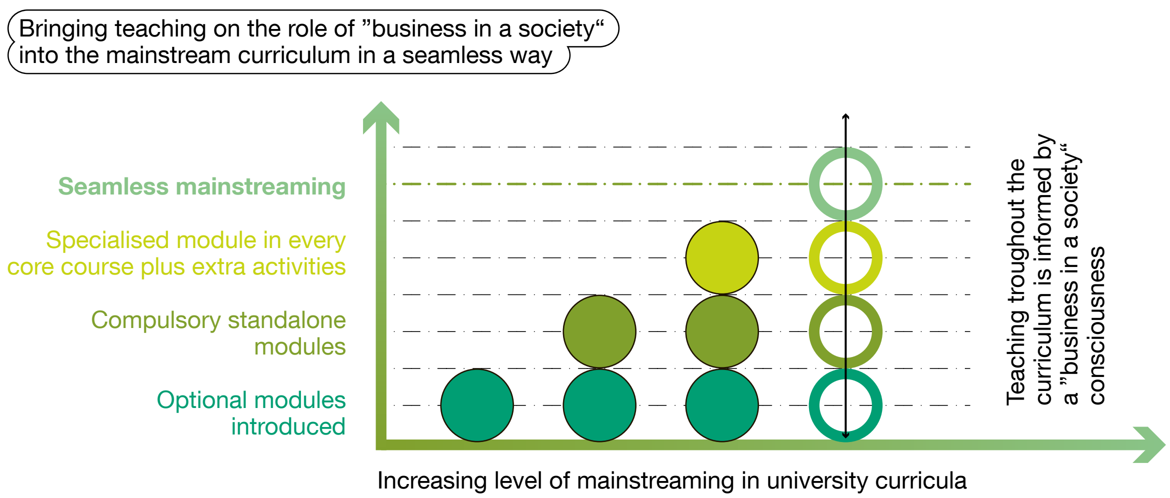


Figure 10: Mainstreaming circularity/sustainability into curricula, Source: based on Gardiner, L., & Lacy, P. (2003).

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# II.4.
# Circular Economy through Digitalization

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**Dr. Sicco Lehmann-Brauns**
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Head of Innovation Forum/International Affairs, acatech

# II.4.1. Recommendations for Action – Working Group IV

**1** We need a powerful digital infrastructure and digitalization which has to be further promoted, especially in the public sector and in SMEs in Germany.

**2** Besides concrete technologies and infrastructures, the importance of standards and norms has to be taken into account.

**3** The already existing digital tools should be tested how far they are able to support and improve the recycling process and resource management in Circular Economy (CE).

**4** Besides digital tools, circular economy needs physics-based system simulation of thermodynamical flows in industrial recycling plants.

**5** The costs and benefits in companies and public administration should clearly be addressed.

**6** Multilateral data exchange along the supply chain and the product life cycle is needed.

**7** Besides established IT-tools, a new promising technology such as blockchain should be applied, tested, and developed.

**8** Besides established IT-tools, a new promising technology such as Artificial Intelligence should be applied, tested, and developed.

**9** It is crucial to develop sustainable business models that are based on Circular Economy (CE) – approaches.

**10** The environmental, economic, and societal balance of digital tools and infrastructures, i. e., their ecological, economic, and societal effects ("Umweltbilanz") in CE is decisive.

## Annotation

**The following texts of Part II.4. have been developed on the basis of contributions from and discussions with the participants of the Working Group "Circular Economy through Digitalisation".**

# Working Group IV – Circular Economy through Digitalisation

## Chairs

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## Group Members

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New Business & Industry Strategy, SAP SE

**Prof. Dr. Holger Kohl**
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Member for the acatech initiative “Circular Economy”

**Prof. Dr. Dr. h.c. mult. Markus Reuter**
Senior Expert, SMS group GmbH, Düsseldorf (since 2020);
Honorary Prof. TU Bergakademie Freiberg, Director Helmholtz Institute Freiberg for Resource Technology, Germany (until 2020);
acatech initiative “Circular Economy”

**Prof. Dr. Dr. Jan-Hendrik Röver, LL.M. (LSE), FRSA**
Managing Director bei goetzpartners

# II.4.2. Explanations

In our recommendations we focus on the potentials of digitalization for Circular Economy as one essential step towards achieving a more sustainable economy. So far, the potential of certain digital technologies could only be shown in isolated use cases. In order to be able to understand comprehensively the potential of digital technologies for closing resource cycles, their modes of action and their interaction in socio-technical application contexts must be systematically investigated. Hereby, any socio-technical advances must be accompanied by appropriate communication strategies since they must be broadly (i) accepted by society and (ii) transferred into business models to ensure their extensive implementation.

1

**We need a powerful digital infrastructure and digitalization which has to be further promoted, especially in the public sector and in SMEs in Germany.**

We need a powerful digital infrastructure and digitalization which has to be promoted further, especially in the public sector and among SMEs in Germany. The conversion of highly complex economic processes with high amounts of data to closed loop resource management can only be successful if these processes are supported by digital infrastructures and technology. This seems to be a necessary condition for the realization of CE.

2

**Besides concrete technologies and infrastructures, the importance of standards and norms has to be taken into account.**

Besides concrete technologies and infrastructures, the importance of standards and norms has to be taken into account. Standards and norms support the emergence of a network of technical solutions and encourage trust and acceptance of technology.

3

**The already existing digital tools should be tested how far they are able to support and improve the recycling process and resource management in Circular Economy (CE).**

Besides concrete technologies and infrastructures, the importance of standards and norms has to be taken into account. Standards and norms support the emergence of a network of technical solutions and encourage trust and acceptance of technology.

4

**Besides digital tools, circular economy needs physics-based system simulation of thermodynamical flows in industrial recycling plants.**

In industrial recycling, we need, for example, certain main metallurgy branches to be able to deal at all with the diverse metal mixtures in modern products. For example, if copper metallurgy is not available, it becomes more difficult to economically extract gold, platinum and other elements. These substances are chemically similar to copper, which is therefore a so-called carrier metal for their extraction. Without copper metallurgy, many refining opportunities would be lost. Accordingly, metals cannot be considered individually, but must be seen in the context of the respective metals present in the mixture. We also have to look at raw materials and energy together, as they are closely linked according to basic laws of thermodynamics. The discourse on digital circular economy is often only about data, but energy is forgotten. Conversely, the energy discussion also often excludes the raw materials that will be needed, for example, for the sustainable energy infrastructures of the future. Only a holistic perspective with exact data can provide the necessary overview to lead digital circular economy to a success.

5

**The costs and benefits in companies and public administration should clearly be addressed.**

The costs and benefits of digitalization in companies and public administration should clearly be addressed. Companies and public administration must be convinced that financial investment into digital tools is a sustainable investment in the future.

**6**

**Multilateral data exchange along the supply chain and the product life cycle is needed.**

Multilateral data exchange along the supply chain and the product life cycle is needed. Circular economy promotes sustainable resource management, waste reduction, and the recycling or upcycling of resources. Greater transparency of product origins will help in reducing consumption and force companies to change what and how they procure resources.

**7**

**Besides established IT-tools, a new promising technology such as blockchain should be applied, tested, and developed.**

Besides established IT-tools, new promising technologies such as blockchain should be applied, tested, and developed. Blockchain, for example, is a new IT-technology which can label all kinds of resources with tokens, giving them a unique digital identifier (similar to a digital coin) that people can track and trade. This makes the value of resources more apparent, facilitating a new system of pricing and trading resources, and incentivizing people to adopt circular behaviors. Therefore, although many applications are still in a testing phase and need mass adoption, we ask for more research and development of blockchain in CE.

The exponential growth of computing power will accelerate the algorithmization of economy and society. Algorithms will increasingly replace economic agents and create decentralized service and supply structures. The database technology blockchain offers an entry scenario for this new digital world. It is a kind of decentralized accounting, which, e. g., replaces banks for the mediation of money transactions between customers by algorithms. This decentralized agency was invented after the global financial crisis of 2008, which was largely caused by human error in national and international central banks.

Blockchain can be presented as accounting via a continuous decentralized database. The bookkeeping is not centrally stored but is stored as a copy on every computer of the participating actors. On each "page" (block) of the accounts, transactions between the actors and security codes are recorded until they are "full" and a new page has to be "opened". Formally, it is an expandable list of data records (blocks) that are linked with cryptographic procedures. Each block contains a cryptographically secure hash of the previous block, a timestamp, and transaction data. New blocks are created by a consensus procedure (e. g., Proof-of-Work algorithm). By the accounting system "blockchain", digital goods or values (currencies, contracts, etc.) can be reproduced at will: "Everything is a copy". After the Internet of Things, the Internet of Values (IoV ) in economy is thus announced. Due to the sequential storage of data in blockchains, one-sided changes are immediately recognizable. Each actor involved would recognize changes in his copy of the blockchain, since for this the blocks linked into each other would have to be "unpacked". In addition, the high computing capacity of the entire network in "block mining" makes blockchains virtually forgery-proof. A decentralized crypto currency works in the following steps:

1. New transactions are signed and sent to all nodes of the actors.
2. Each node (actor) collects new transactions in a block.
3. Each node (actor) searches for the so-called nonce (random value) that validates its block.
4. If a node (actor) finds a valid block, it sends the block to all other nodes (actors).
5. The nodes (actors) only accept the block if it is valid according to the rules:
   a) The hash value of the block must correspond.
   b) All transactions must be signed correctly.
   c) The transactions must be covered according to the previous blocks (no duplicate output).
   d) New issues and transaction fees must comply with accepted rules.
6. The nodes (actors) express their acceptance of the block by adopting its hash value into their new blocks.

The transactions contained in the new block are initially confirmed only by the participant who created the block. They have only limited credibility. However, if the block has also been accepted as valid by the other participants, they will enter its hash value in their new blocks to be created. If the majority of participants consider the block to be valid, the chain will continue to grow fastest from this block. If they do not consider it valid, the chain will continue to grow from the previous block. Therefore, the blocks form a tree.

Only the chain longest in the first block (root) of the tree is considered valid. Thus, this form of accounting automatically consists of those blocks that have been accepted as valid by the majority. This first block, which is used to start a crypto currency, is called the Genesis block. It is the only block that does not contain a hash value of a predecessor.

The Bitcoin network, for example, is based on a decentralized database (blockchain) managed jointly by the participants using Bitcoin software, in which all transactions are listed. Instead of confidants and institutions (e. g., banks, state currency control, central banks), computationally complex and practically forgery-proof algorithms are used (e. g. proof-of-work algorithm). Proof of ownership of Bitcoin can be stored in a personal digital wallet. Bitcoin's conversion rate to other means of payment is determined by supply and demand. This can trigger speculative bubbles, which is currently still a problem for the general acceptance of Bitcoin.

In general, block chain will be an entry-level technology for a decentralized digital economy in which people as customers and citizens realize their transactions and communications directly and without intermediaries.

The perspective of this technology is by no means limited to banks and monetary transactions. Future developments are also conceivable, in which monitoring and controlling of recycling and other circular processes in digital economy are replaced by algorithms. What at first glance appears to be very grassroots democracy, turns out to be anything but democratic on closer analysis. The basic idea of democracy is that regardless of their position and arrival, everyone has only one vote: One person – one vote! In fact, the power of influence at, for example, Bitcoin depends on the computing power with which a customer asserts himself in the realization of a new block: the greater the available computing power, the greater the probability and confidence that someone can solve the cryptographic task and thus guarantee security (proof-of-work).

With growing blockchain, these tasks become more and more complex and computationally intensive. But computing intensity is also energy intensive. The fact that computation-intensive algorithms consume enormous amounts of energy is hardly considered. In November 2017, Bitcoin's computing network consumed as many kilowatts per hour as the entire country of Denmark. Therefore, countries with cheap energy and cooling for hot supercomputers can produce most Bitcoins (e. g., China). Unless countermeasures are taken and improvements made, such infrastructures in no way promise the salvation of a direct democracy, but rising energy problems (and thus growing environmental problems). In the end, digitization depends on the overall balance of better infrastructure, less energy consumption, a better environment, and more democracy.

**8**

**Besides established IT-tools, a new promising technology such as Artificial Intelligence should be applied, tested, and developed.**

Besides established IT-tools, new promising technologies such as Artificial Intelligence should be applied, tested, and developed. AI opens new avenues to various aspects of sustainability: In agriculture, drones or sensor-based monitoring can be applied to assess the condition of plants in a more economic and ecological way. In production, energy consumption can be reduced through networking and robotics. Product life can be extended by means of predictive maintenance. In recycling and waste management, AI can improve the identification and sorting of waste. For building efficiency and energy management, AI offers improved system control, regulation of heating, cooling, and ventilation systems. In short: Machine learning should help to accelerate and optimize supply chains and help circulate products, components, and materials.

Up to now, the Internet has only been a database with signs and images whose meaning emerges in the user's mind. In order to cope with the complexity of the data, the network must learn to recognize and understand meanings independently. This is already achieved by semantic networks that are equipped with expandable background information (ontologies, concepts, relation, facts) and logical reasoning rules in order to supplement incomplete independently knowledge and draw conclusions. For example, people can be identified, although the data entered directly only partially describe the person.

With Facebook and Twitter, we are entering a new dimension of data clusters. Their information and communication infrastructures create social networks among millions of users. Facebook was created as a social network of universities (at Harvard in 2004). Social and personal data are always online. Data is by no means just text, but also images and sound documents. However, while the traditional Internet only supports communication between people in global computer networks, sensor technology opens up new possibilities for the future. A new dimension of communication: commodities, products, goods, and objects of all kinds can be equipped with sensors to exchange messages and signals. The Internet of persons transforms into the Internet of Things (IoT):

In the Internet of Things, physical objects of all kinds are equipped with sensors (e. g., RFID chips) to communicate with each other. This enables automation and self-organization of technical and social systems (e. g., factories, companies, organizations). Hidden RFID and sensor technology creates the Internet of things that can communicate with each other and with people. For the Internet of Services, offers and technologies in the area of online commerce or online services and the media industry will be comprehensively expanded. Big data refers to the amount of data generated and processed on the Internet of Things. Not only structured data (e. g. digitized documents, e-mails) is recorded, but also unstructured data from sensors, which is generated by signals in the Internet of Things. The growing variety and complexity of services and possibilities in the network leads to an exponential data explosion. From petabytes (peta=10^15) up, an amount of data is called Big Data.

In the digital world, according to current estimates, the global volume of data doubles every two years. Under the term "Big Data" experts summarize two aspects: on the one hand the ever faster growing mountains of data, on the other hand IT solutions and management systems with which scientific institutions and companies can evaluate, analyze, and derive knowledge from data. The industry that has developed around the collection, processing, and use of data is one in which corporations such as Google, Facebook, and Amazon are just the best-known representatives. Thousands of other companies thrive on generating, linking, and reselling information – a gigantic market. Big Data technology provides management with a significantly improved basis for time.

Big Data refers to data sets of circular economy whose size and complexity (petabyte range) is not possible due to traditionall databases and algorithms for collecting, managing, and processing data at manageable costs and in the foreseeable future. Three trends need to be integrated:

- massive growth of transaction data volumes (big transaction data),
- explosive increase of interaction data (big interaction data): e.g. social media, sensor technology, GPS, call logs,
- new highly scalable and distributed software (Big Data processing): e.g., Hadoop (Java) and MapReduce (Google).

Big Data initially means huge amounts of data: Google handles 24 petabytes a day, YouTube has 800 million monthly users, Twitter registers 400 million tweets a day. Data is analog and digital. It concerns books, pictures, e-mails, photographs, television, radio, but also data from sensors and navigation systems. It is structured and unstructured, often not exact, but exist in masses. By using fast algorithms, it should be transformed into useful information. This means the discovery of new connections, correlations, and the derivation of future prognoses.

However, forecasts and maintenance of products are not necessarily extrapolated on the basis of representative samples using conventional statistical methods. Big data algorithms evaluate all data in a data set, however large, diverse and unstructured it may be. What is new about this evaluation is that the contents and meanings of the data records do not have to be known in order to be able to derive information.

This is possible by so-called metadata. What this means is that we do not need to know what someone is talking about on the phone, but the movement pattern of the respective mobile phone is decisive. A precise movement pattern of the mobile phone user can be determined over a certain period of time from a data retention memory, since the local radio cells are switched on with every automatic e-mail query and another use. In Germany, there are about 113 million mobile phone connections whose sensors and signals function like a measuring device. The data in an e-mail refers to the text of the content. Metadata of the e-mail is, e.g., sender, recipient, and the time of sending. In the immersion project of the Media Lab of MIT (Massachusetts Institute of Technology), graphs are automatically drawn from such metadata. In an earlier experiment at MIT, motion patterns of 100 people had been determined over a recording period of 450,000 hours. This made it possible to determine who met whom and how often at certain locations. Places were grouped as workplace, home and others. On the basis of corresponding patterns of metadata, economic and ecological networks could be supervised with a high probability.

Often, however, predictions can only be derived from metadata if the correct contexts are known. Today, however, there are databases and background information on the Internet with which the meanings can be made accessible. In principle, this development of meanings works like a Semantic Web. The discovery of an American bioinformatician who used metadata alone to determine the name of an anonymous donor of human genetic material was spectacular. Metadata related to the age of the donor and the name of the American state in which the donation was made. The bioinformatician limited the search by combining place and age and used an online search engine in which families entered the genetic code for genealogical research. In the process, family members of the wanted persons emerged, whose data she combined with demographic tables, in order to finally find what they were looking for.

As long as the causal causes of a data correlation are not known and not understood, the mass evaluation of data and the calculation of correlations only help to a limited extent: "Correlation is no causation!"

Thus, predicative modeling is the central goal of Big Data mining as part of data science. Algorithms of machine learning are used for this purpose which enable self-improving and self-repairing of production cycles. We rely more and more on efficient algorithms, because otherwise the complexity of our economic infrastructure would not be manageable: Our brains are too slow and hopelessly overwhelmed by the amount of data we have to deal with. But how secure are AI algorithms? In practical applications, learning algorithms refer to models of neural networks, which themselves are extremely complex. They are fed and trained with huge amounts of data. The number of necessary parameters explodes exponentially. Nobody knows exactly what happens in these "black boxes" in detail. A statistical trial-and-error procedure often remains. But how should questions of responsibility be decided in, e.g., autonomous car driving or circular economy, if the methodological basics remain dark? In machine learning with neural networks we need more explanation (explainability) and attribution (accountability) of causes and effects in order to be able to decide ethical and legal questions of responsibility!

**9**

**It is crucial to develop sustainable business models that are based on Circular Economy (CE) – approaches.**

It is crucial to develop sustainable business models that are based on Circular Economy-approaches. There are already promising case studies for Circular Economy through digitalization: Examples which we considered carefully concern sustainable urban housing, sustainable smart city ("Munich as digital twin"), metallurgical recycling potentials, and recycling processes of plastic.

**10**

**The environmental, economic, and societal balance of digital tools and infrastructures, i.e., their ecological, economic, and societal effects ("Umweltbilanz") in CE is decisive.**

The environmental, economic and societal balance of digital tools and infrastructures, i.e. their ecological, economic, and societal effects ("Umweltbilanz") in Circular Economy is decisive for successfully implementing a more sustainable economy. For example, efficiency of digital applications and their economic and ecological costs of energy consumption must be balanced to improve the benefits of a circular economy. In this respect, the traceability of products and product properties across the value chain and the product life cycle is becoming increasingly important. Digital product passports offer great potential here, as they allow specific product data to be made available. They allow to transparently determine product locations and properties and present both the requirements demanded by political regulation and those increasingly in demand on the market with regard to the ecological and social footprint of a product. Digital product passports can be particularly helpful in industrial sectors with high resource consumption and recycling challenges, e. g. electronic devices, batteries or cars.

**Finally, group IV recommends the following three main actions:**

- We need a powerful digital infrastructure and digitalization which has to be promoted further, especially in the public sector and among SMEs in Germany.
- Besides established IT-tools, new promising technologies such as blockchain and AI should be applied, tested, and developed.
- The environmental, economic and societal balance of digital tools and infrastructures, i.e. their ecological, economic, and societal effects ("Umweltbilanz") in CE is decisive for successfully implementing a more sustainable economy.

# Part III

## Student Internship Circular Economy

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# An International Project Laboratory on Circular Economy

In the winter semester 2020/2021, a project laboratory on CE took place at the Chair of Renewable and Sustainable Energy Systems of Prof. Dr. Thomas Hamacher. TU-Munich increasingly offers project laboratories as teaching concepts in some degree programs, including the Faculty of Electrical Engineering and Information Technology. In the Faculty of Economics, project studies are part of the TUM-BWL course. Study programs at the TUM locations Straubing and Weihenstephan are also considered. The CDTM is also conceptually linked to study projects.

As a rule, in a project internship/study project, three to four students work together on a project topic in cooperation with external partners over a period of several months. The effort amounts to about one working day a week over a whole semester.

Such a format was also chosen here. Under the coordination of Prof. Hamacher and Ms. Andrea Cadavid Isaza, four student groups were formed around the main topic of "Circular Economy".

**Group 1**
Circular Economy and Economic Theory & Practice

**Group 2**
Circular Economy andd Energy Efficiency

**Group 3**
Resource Efficiency through Circular Economy

**Group 4**
Circular Economy through Digitalization

Project topics should start with questions of product development, through questions of how to significantly increase product life, to methods of recycling and urban mining. Issues of government regulation were to be addressed as well as the impact on the individual and overall economy.

It was a primary task of the participants to recruit an industry partner with content related to circular economy issues. PhD Students from foreign partner universities were also included in the group of participants in the internship (Figure 1).

All project internships (study projects) took place in the winter semester 2020/21. The selection of the students and the project supervision is done by coordination of Prof. Hamacher and Ms. Andrea Cadavid Isaza. Some Emeriti of Excellence, who acted as Chairs for the preparations of the TUM Symposium on Circular Economy, were involved as companions of the students both in the assignment and in the interim and final presentations of the project groups. The final presentations with the results of the project practices took place on February 11, 2021 as a Zoom session.

Selected members from each student project group (selected after the final presentation) presented the results at the April CE Symposium workshops. We gained one more experience: The internship showed us that in the future university teaching can easily be done at more than one university due to modern communication technologies. This opens up completely new opportunities for national and international cooperation.

The project internship proved to be a pilot project for further preparations for the TUM Symposium. In this way, it was possible to close the circle of the TUM Senior Excellence Faculty‘s student training initiative.

| Topic | Mr/Ms | First Name | Last Name | Program/University |
|---|---|---|---|---|
| **Circular Economy and Economic Theory & Practice** | Mr | Donald Chidera | Abonyi | M.Sc. Power Engineering |
| | Ms | Anna Sophia | Braunfels | M.Sc. Sustainable Resource Management |
| | Ms | Julia | Mengele | M.Sc. Management & Technology |
| | Mr | Denis | Fraga | Imperial College London |
| **Circular Economy and Energy Efficiency** | Ms | Kristina | Lyapcheva | M.Sc. Sustainable Resource Management |
| | Ms | Pin-Zhen | Shen | M.Sc. Sustainable Resource Management |
| | Mr | Felipe | Vega | M.Sc. Management & Technology |
| | Ms | Chaitali | Joshi | Ahmedabad University |
| **ResourceEfficiency through Circular Economy** | Mr | Atta Ur | Razzaq | M.Sc. Power Engineering |
| | Ms | Tamara | Salas | M.Sc. Sustainable Resource Management |
| | Ms | Szimona | Zaharieva | M.Sc. Sustainable Resource Management |
| | Mr | Philip | White | University of Texas in Austin |
| **Circular Economy through Digitalization** | Ms | Sina | Dupslaff | M.Sc. Sustainable Resource Management |
| | Mr | Adam | Misik | M.Sc. Elektrotechnik und Informationstechnik |
| | Ms | Laura | Zwick | M.Sc. Sustainable Resource Management |
| | Mr | Yu | Zhang | Imperial College London |

Figure 1 shows the structure and list of participants of the Circular Economy project internship.

# Part IV

## Circular Economy in Research and Education at TUM

# IV.1.
# CirculaTUM

# IV.1.1. CirculaTUM – Speakers and Members

01

**Prof. Dipl-Ing. Stephan Birk**
Chair of Architecture and Timber Construction, TUM.wood

02

**Prof. Dr.-Ing. André Borrmann**
Chair of Computational Modelling and Simulation

03

**Prof. Dr. Thomas Brück**
Werner Siemens-Chair of Synthetic Biotechnology

04

**Prof. Dr. Claudia Doblinger**
Assistant Professor of Innovation and Technology Management

05

**Prof. Dr.-Ing. Jörg E. Drewes**
Chair of Urban Water Systems Engineering

06

**Prof. Dr. Gunther Friedl**
Chair of Management Accounting

07

**Dr. Philipp Gerbert**
General Managing Director
TUM Venture Labs

08

**Prof. Dr. Sebastian J. Goerg**
Professorship of Economics

09

**Prof. Dr. Helmut Krcmar**
Chair of Information Systems and Business Process Management

10

**Prof. Dr. Svetlana Ikonnikova**
Professorship of Resource Economics

11

**Prof. Dr.-Ing. Werner Lang**
Chair of Energy Efficient and Sustainable Design and Building

12

**Prof. Dr.-Ing. Markus Lienkamp**
Chair of Automotive Technology

13

**Prof. Dr. Peter Mayr**
Chair of Materials Engineering of Additive Manufacturing, TUM.Idea

14

**Prof. Dr. Alwine Mohnen**
Chair of Corporate Management

15

**Prof. Dr.-Ing. Frank Petzold**
Chair of Architectural Informatics

16

**Prof. Dr. Clarissa Prazeres da Costa**
Institute for Medical Microbiology, Immunology and Hygiene (MIH)
Center for Global Health

17

**Prof. Dr. Klaus Richter**
Chair of Wood Science, TUM.wood

18

**Prof. Dr. Hubert Röder**
Professorship of Sustainable Business Economics

19

**Prof. Dr. Jutta Roosen**
Chair of Marketing and Consumer Research

20

**PD Dr. Christian Schulz**
Klinikum rechts der Isar,
Clinic for Anesthesiology and Intensive Care Medicine

21

**Prof. Dr. Miranda Schreurs**
Chair of Environmental and Climate Policy

22

**Prof. Dr. Clemens Thielen**
Professorship of Complex Networks

23

**Prof. Dr. Isabell M. Welpe**
Chair of Strategy and Organization

24

**Prof. Dr. Stefan Wurster**
Professorship of Policy Analysis

25

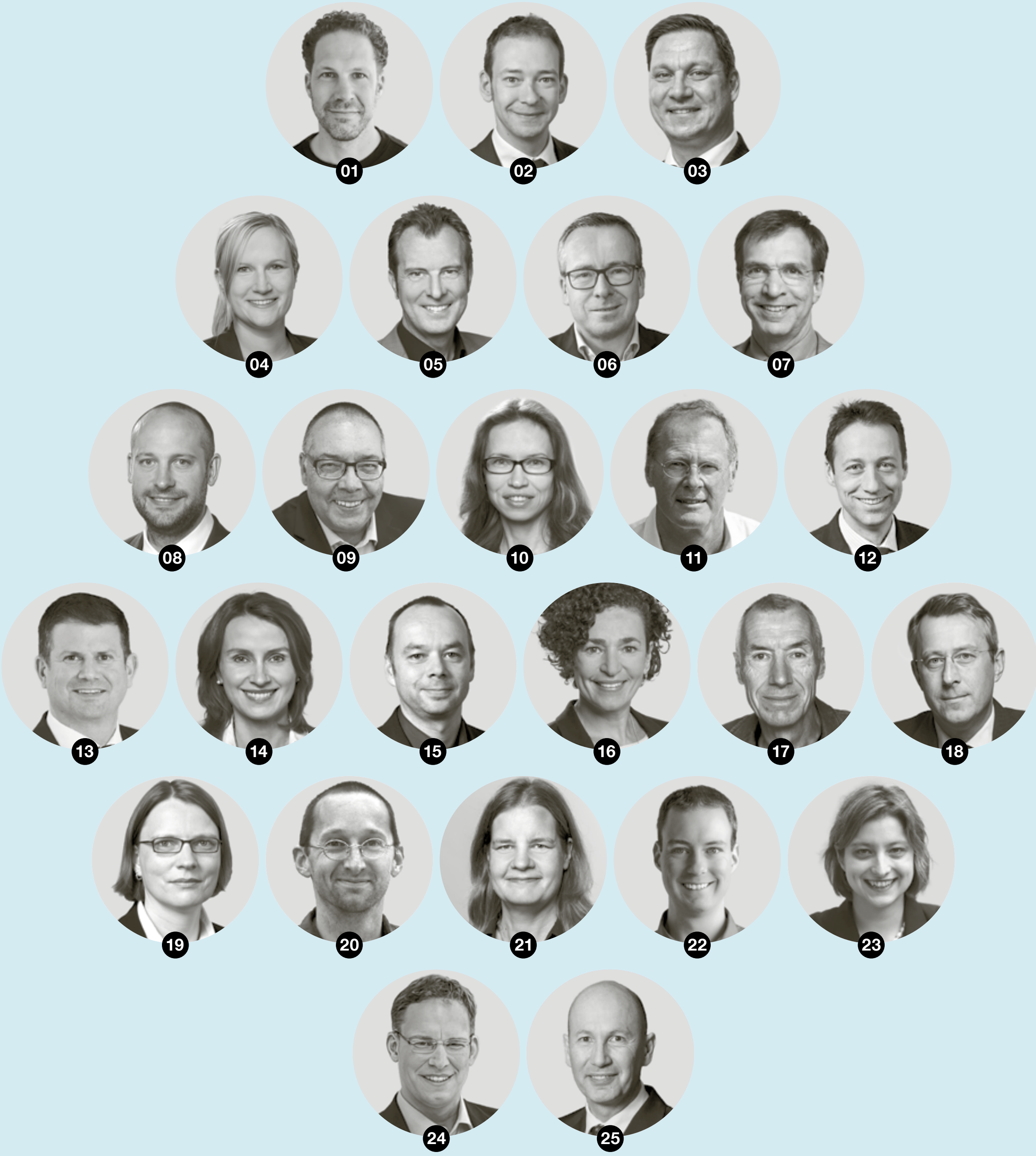
**Prof. Dr.-Ing. Michael Zäh**
Institute for Machine Tools and Industrial Management

# Speakers

**Prof. Dr.-Ing. Johannes Fottner**
Chair of Material Handling, Material Flow and Logistics

**Prof. Dr. Magnus Fröhling**
Professorship of Circular Economy

# Members



# IV.1.2. CirculaTUM – the TUM Alliance for Circular Economy in Research, Education and Transfer

Johannes Fottner, Magnus Fröhling, Vanessa Heinrich, Niclas-Alexander Mauss

Universities can play a key role for the success in the transition towards a Circular Economy. This is particularly true for the Technical University of Munich with its research and teaching profile, as well as in terms of its self-conception as an entrepreneurial university and servant of society.

For this reason, the university-wide research alliance CirculaTUM was established. CirculaTUM bundles the diverse competencies of TUM across all disciplines and locations. This provides essentially the breadth and depth of necessary competencies. Bringing these together facilitates to shape the paradigm shift from the traditional, linear economy and society towards a circular model.

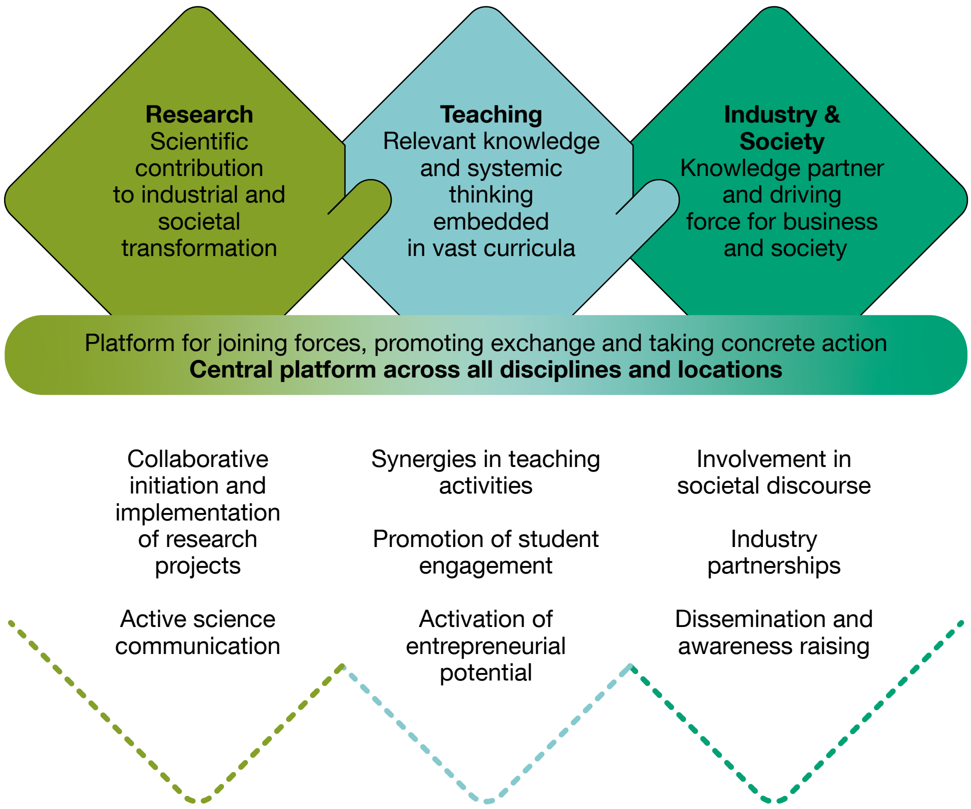
In doing so, CirculaTUM initiates new research projects, supports teaching and training of systems thinking and further competencies needed for the CE, and – in close cooperation with UnternehmerTUM and the TUM Venture Labs – contributes to the activation of student engagement and entrepreneurial potential. Far beyond the boundaries of the university, CirculaTUM acts as a driving force and actively promotes exchange with business and society in order to make a scientific contribution to industrial and societal transformation.

Reflecting both essential fields of action and the competence profile of TUM, the CirculaTUM network splits into the three focal areas of Industrial Value Creation, Built Environment and Natural Cycles/Bioeconomy. The first aims at the transformation of the manufacturing industry and the development of technology and process solutions to close industrial material cycles and enable new sustainable business models. The second targets at holistic resource efficiency in building design and construction processes but also the man-made environment we live in as a whole. The latter focuses on the regeneration of the biosphere through the use and restoration of renewable value streams in agriculture/forestry and basic material production.

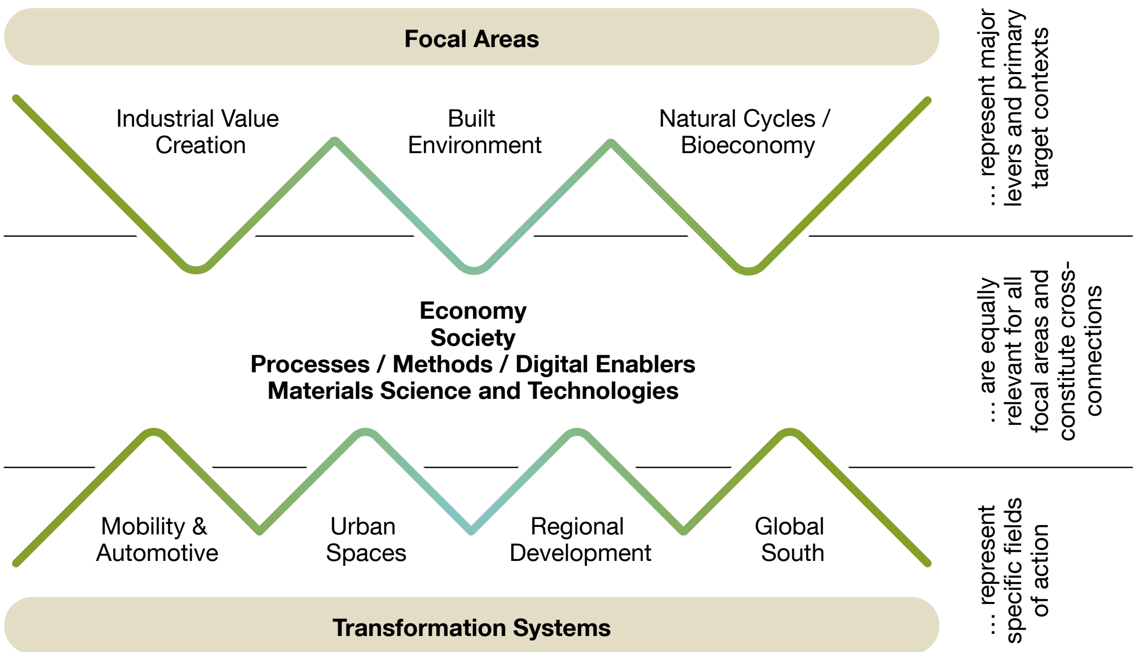
The cross-sectional fields of policies, economics and management, society, digitalization, technologies, and materials science are relevant in different ways to all of the above focal areas. Several particularly significant transformation systems undergoing profound upheavals represent specific fields of application for the focal areas and their cross-cutting themes. Implementation paths developed in these are to be transferred to other contexts.

# CirculaTUM – Vision and Mission

Capabilities and responsibility to actively shape
the transition to a Circular Economy




# Structure of the research network



# IV.2.
# TUM Campus Straubing for Biotechnology and Sustainability

# IV.2.1. TUM Campus Straubing for Biotechnology and Sustainability Board and Members

01
**Prof. Dr. Bastian Blombach**
Microbial Biotechnology

02
**Prof. Dr.-Ing. Jakob Burger**
Chemical Process Engineering

03
**Prof. Dr. Rubén Dario Costa Riquelme**
Biogenic Functional Materials

04
**Prof. Dr. Claudia Doblinger**
Innovation and Technology Management

05
**Prof. Dr. Magnus Fröhling**
Circular Economy

06
**Prof. Dr.-Ing. Matthias Gaderer**
Regenerative Energy Systems

07
**Prof. Dr. Sebastian Goerg**
Economics

08
**Prof. Dr. Dominik Grimm**
Bioinformatics

09
**Prof. Dr. Alexander Hübner**
Supply and Value Chain Management

10
**Prof. Dr. Josef Kainz**
Energy Technology

11
**Prof. Dr. Klaus Menrad**
Marketing and Management of Biogenic Resources

12
**Prof. Dr. Nicolas Plumeré**
Electrobiotechnology

13
**Prof. Dr. Andreas Pondorfer**
Sustainable Economic Policy

14
**Prof. Dr. Herbert Riepl**
Organic and Analytical Chemistry

15
**Prof. Dr. Hubert Röder**
Sustainable Business Economics

16
**Prof. Dr.-Ing. Torsten Stelzer**
Separation Engineering for Aqueous Systems

17
**Prof. Dr. Clemens Thielen**
Complex Networks

18
**Prof. Dr. Thomas Vienken**
Geothermal Energy

19
**Prof. Dr.-Ing. Michael Zavrel**
Bioprocess Engineering

20
**Prof. Dr. Cordt Zollfrank**
Biogenic Polymers

# Board

**Prof. Dr. Volker Sieber**
Rector,
Chemistry of Biogenic Resources

**Prof. Dr. Anja Faße**
Prorector,
Environmental Policy and Resource Economics

# Members

# IV.2.2. Education and Research for the Bioeconomy – How to go across disciplines

Christin Fellenberg, Volker Sieber

On our way to achieve a sustainable society on our precious and vulnerable planet the Bioeconomy is an essential concept going hand in hand with that of the Circular Economy. The German Bioeconomy Council regards the bioeconomy as a key element of the social transformation towards a more sustainable economic system. Bioeconomy is defined as the production and utilization of biological resources as well as biological principles to provide products, processes and services in all economic sectors within the framework of a sustainable economic system (https://biooekonomierat.de/biooekonomie/).

Both, the bioeconomy and the circular economy, are inter- and multidisciplinary concepts focusing on the achievement of sustainability and climate change mitigation goals. Both concepts complement each other and partially overlap, offering huge potentials for synergies. For example, circular economy depends on the substitution of non-renewable natural resources with biomass and therefore on the progress of the bioeconomy. The other way around, the bioeconomy utilizes strategies from the circular economy such as cascade use and loops of biogenic materials.

In order to achieve the successful implementation of bioeconomy and circular economy, among others, a highly skilled and multidisciplinary graduate workforce is required that can think and act transdisciplinary. In addition, highly interdisciplinary research to provide new technologies and innovations is required.

The TUM Campus Straubing (TUMCS), an Integrative Research Institute of the Technical University of Munich, contributes to achieving these goals. At the TUMCS professors and their workgroups from all disciplines of TUM are brought together underneath one roof away from their Home Schools to foster strong interactions across the boundaries of their subjects. The TUMCS as such stands for interdisciplinary research and teaching in the bioeconomy and circular economy for the realization of a sustainable change in raw materials and energy in all areas of life.

Central areas of research are, for example, the establishment of new and innovative high-performance technologies for the material and energetic use of biogenic and other regenerative raw materials as well as their economic evaluation. In addition, the TUMCS supports innovations in the bioeconomy by developing business models, as well as new products and technologies and bringing them to market maturity with the central goal of a sustainable economy.

In order for the raw material and energy transition to succeed in a forward-looking and sustainable manner, the economy needs experts and multidisciplinary-trained specialists and managers. The courses of study at the TUMCS serve to train specialized top experts, while the broad-based training with individually set focal points takes into account the demand for interdisciplinary in the complex subject areas of bioeconomy. The TUMCS offers along with the central research topics, five thematic key areas corresponding to the study programs Bioeconomy, Sustainable Management and Technology, Biogenic Materials, Chemical Biotechnology, Technology of Biogenic Resources. All study programs are designed to train subject-specific experts for example in the field of business management, economics, material science, biotechnology or engineering while at the same time foster transdisciplinary thinking and cross boundary knowledge gain. For this, the curricula of the individual study programs include aspects of the other disciplines to provide multidisciplinary perspective all centered around the subjects of sustainability. This enables the education and training of subject-specific and individualized multidisciplinary experts who can actively drive and shape the raw material and energy transition with the corresponding target competences for the individual companies, the entire economy and society.

The key to success of the TUMCS and its approach to enable the bioeconomy is in building the one roof, as stated above, to merge the colleagues from the different disciplines away from the often entrenched thinking within schools. This is even enhanced by the location of the TUMCS in a thriving bioeconomy region in Eastern Bavaria, where strong agricultural and forest production are met by entrepreneurial activities and big companies in the area of biomass utilization. Within this thriving environment, bioeconomy and sustainability become the focus around which all orientate, students and researchers alike.

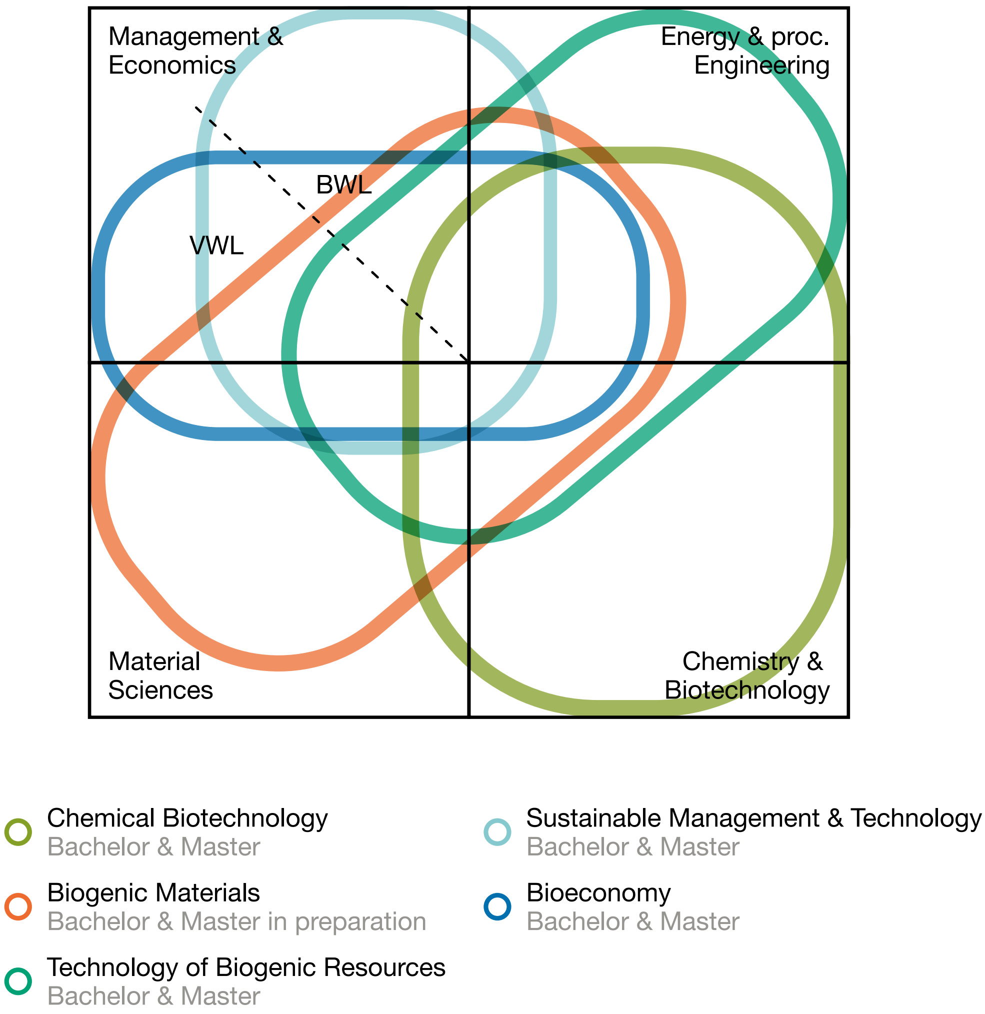



Figure 1: Interdisciplinary Education at TUMCS

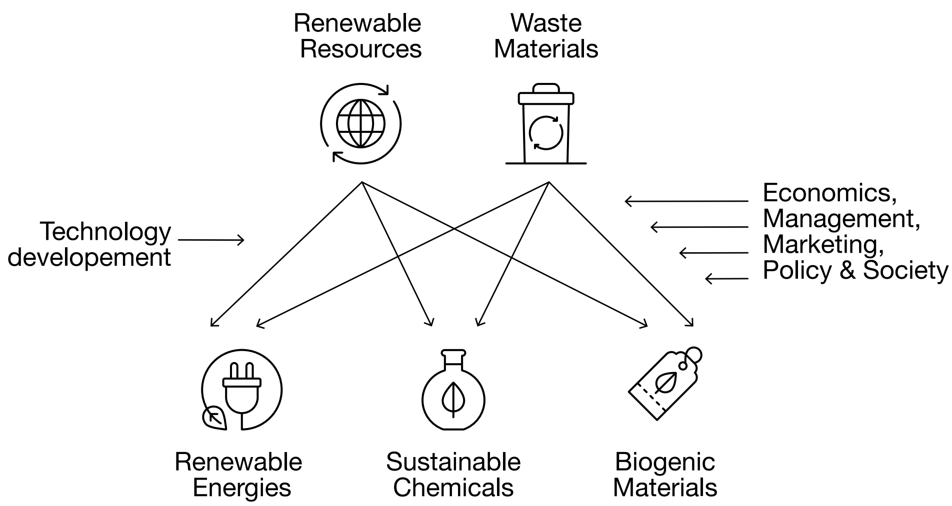



Figure 2: Interdisciplinary Research at TUMCS

# Part V

## TUM Forum Sustainability

**Dr. rer. nat. Birgit Herbst-Gaebel**
Microbiologist/Immunobiologist;
Science Manager,
TUM Senior Excellence Faculty

**Prof. Dr. Dr. h.c. Michael Molls**
Speaker of the TUM Senior Excellence Faculty;
Director of the TUM Institute for Advanced Study (IAS);
Professor and former Director of the Clinic for Radiotherapy
and Radiological Oncology, TUM

# TUM Forum Sustainability – an Initiative of TUM Senior Excellence Faculty

This book "Circular Economy" summarizes the outcome of the corresponding symposium in summer 2021. The symposium is part of the series of initiatives "TUM Forum Sustainability" (figure 1), which was founded in 2016 by the TUM Senior Excellence Faculty[1]. The activities are organized regularly in cooperation with the Institute for Earth System Preservation (IESP)[2] and the TUM Institute for Advanced Study (IAS)[3].

### TUM Forum Sustainability – Motivation

We live in a time of great threats to our environment and existential challenges for mankind. Innovations aimed at "sustainability" (compare with the UN Sustainability Goals) are needed urgently. "Sustainability" is a complex and multi-domain issue with significant definitional conflicts in theory and practice. The TUM Senior Excellence Faculty has been providing important impulses here with its TUM Forum Sustainability series since 2016.

**Goals**

- Elaborating and formulating recommendations to science, society, entrepreneurs, politics
- Bringing the idea of "sustainability" and "research" as a Technical University into the public eye
- Networking of disciplines
- Acting as a catalyst to initiate and sustain important discussions

**Activities**

- Scientific expert symposia in the format of the "Dahlem Conferences"
- Symposia and events for the general public
- Publications such as books, brochures, abstract volumes

### TUM Senior Excellence Faculty

The TUM Emeriti of Excellence, members of the interdisciplinary TUM Senior Excellence Faculty (SEF), can look back on many years of very successful research, teaching and organizational activities. They are committed beyond their own discipline.
The SEF brings together a wide range of experience in science, management, national and international relationships and responsibility towards society.
With its TUM Forum Sustainability series, the SEF takes up pressing issues and central topics of the university and society in order to further develop ideas and trigger initiatives. As a bridge builder and catalyst in science and modern "techno society", the SEF gives broad space to discussion. A particular concern is to make it clear that research and its potential are the engine of progress for modern societies and their sustainable further development.

**1**

In 2021, the book "Strategies for Sustainability" was published, in which experts present considerations and proposals on how to think in a wide variety of application worlds of modern civilization in order to confidently move into a future characterized by sustainability. The book is based on the expert symposium "Violated Earth – Violent Earth" of the TUM Forum Sustainability series in 2019. A documentary video was also produced as part of this symposium.

**2**

The book "Science, Reason & Sustainability – Forward Thinking for the Post-Corona Era" is an anthology produced at the beginning of the Corona pandemic with about 90 interdisciplinary articles by 84 authors from different disciplines. It includes nine chapters on highly relevant social topics. It is available in German and English.
Print Version (english): http://go.tum.de/501907

Free Download
**German Version**
mediatum.ub.tum.de/1548492

Free Download
**Englisch Version**
mediatum.ub.tum.de/1578813

**3**

More than 450 participants, including representatives of scientific institutions, several African consulates, Bavarian state ministries and the interested public attended the symposium "Sustainable Development in Africa" with great enthusiasm. The symposium was organized by the TUM Senior Excellence Faculty in cooperation with the "TUM School of Governance" on the occasion of the 150th anniversary of TUM. Participants learned about TUM's current projects in Africa during the lectures and the accompanying poster exhibition. Many visitors joined in when the challenges of "Governance and Education in Africa" were discussed at the top-class round table.

**4**

The idea and content of the book "Sustainable Risk Management" were developed in 2016 as part of an expert workshop held by TUM Senior Excellence Faculty and IESP. In the book, experts describe approaches that can support both decision-makers and the affected population in overcoming unjustified fears and developing policies based on scientific evidence. Four exemplary focus areas were selected for in-depth examination:

- The scientific basis of risk management
- Risk management in environmental and ecological policy
- Risk management in radiation medicine
- Risk management in the context of digitalization and robotics

General as well as specific recommendations are summarized in a memorandum.

1 TUM Senior Excellence Faculty: www.emeriti-of-excellence.tum.de
2 Institute for Earth System Preservation: www.iesp.de
3 TUM Institute for Advanced Study: www.ias.tum.de


Figure 1: TUM Forum Sustainability – Activities and Publications

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